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Safeguards for High-Level Waste Repositories

Final Report
February 1979 - September 1980

Prepared by J. Stoddard, L. Harris, J. Walkush, M. Hecht

Science Applications, Inc.

Prepared for
U.S. Nuclear Regulatory
Commission

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Prepared by
J. Stoddard, L. Harris, J. Walkush, M. Hecht

Science Applications, Inc.
1200 Prospect Street
La Jolla, CA 92037

Prepared for
Division of Safeguards
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. B6376-9

ABSTRACT

This report provides the results of a study to assist the NRC in establishing a technical basis for the examination and resolution of safeguards issues related to high-level waste repositories. In this study, requirements for a NRC-licensed high-level geologic waste repository are derived. The high-level waste repository is assumed to accept wastes from any of several commercial light water power reactor fuel cycles including once-through (in which spent fuel is buried), uranium only recycle (in which reprocessed wastes including cladding hulls, fission products and transuranic wastes are buried), and uranium-plutonium recycle.

The security requirements are assumed to result from three potential threats to public health and safety: on-site radiological sabotage, theft for the purpose of off-site radiological dispersal, and theft for the purpose of producing a nuclear explosive. For the latter threat objective, i.e., theft for production of a nuclear explosive, both domestic and international safeguards requirements are considered.

ABSTRACT

This report provides the results of a study to assist the NRC in establishing a technical basis for the examination and resolution of safeguards issues related to high-level waste repositories. In this study, [illegible] for a DOE-licensed high-level geologic waste repository [illegible]. The high-level waste repository is assumed to accept wastes from any of several commercial light-water power reactor fuel cycles including [illegible] only recycle [illegible] in which [illegible] wastes including [illegible] fission products and [illegible] uranium-plutonium recycle.

The [illegible] requirements are [illegible] from three [illegible] a nuclear [illegible]

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EXECUTIVE SUMMARY

This report gives the results of a study performed to assist the NRC in establishing a technical basis for the examination and resolution of safeguards issues related to high-level waste repositories. In this study potential security requirements for a NRC-licensed high-level geologic waste repository are derived. The high-level waste repository is assumed to accept wastes from any of three commercial light-water power reactor fuel cycles, including once-through, uranium-only recycle and uranium-plutonium recycle.

The security requirements are assumed to result from three potential threat activities to public health and safety. These three threat activities are on-site radiological sabotage, theft for the purpose of off-site radiological dispersal, and theft for the purpose of producing a nuclear explosive.

The potential consequences of on-site radiological sabotage and of theft for off-site dispersal were first calculated for reference release events to determine the need for security protection. The consequences were found to be strongly dependent on the waste type; however, the radiological sabotage consequences for all high-level waste types considered were sufficient to justify some physical protection measures.

Because the potential consequences vary greatly with waste type and repository site location, different levels of protection are appropriate. Physical security systems for four different levels of protection were defined. This permits the application of a level of protecton appropriate to the sabotage consequence. Thus, a remotely-located repository containing a waste type such as spent fuel or vitrified high-level waste need be given only a relatively low level of protection, while a rurally-located repository accepting a waste type such as calcined high-level waste can be given a high level of protection.

Security measures for the four different levels of protection were derived from current and proposed NRC rules for nuclear facilities, materials and operations with similar levels of potential sabotage consequences. Figure ES-1 illustrates the procedure used in this derivation. First (Step 1), the level of protection, based on current NRC policy, versus the potential level of consequences was determined for several nuclear facilities, materials and activities. This yielded a relationship (the dashed curve) which (in Step 2) was subsequently used to derive the level of protection appropriate for high-level waste repositories with different consequence categories. As an example, it was determined that the potential radiological sabotage consequences for a rurally-located repository accepting the highest consequence waste material (spray-calcined HLW with plutonium) were of the same general magnitude as the potential consequences for a nuclear power reactor category 1 accident. Therefore, the security measures derived for protection of that repository are similar to the physical security measures currently required by NRC for the protection of operating nuclear power reactors.* Definitions of the four levels of security protection are given in Figure ES-2; a detailed description of the corresponding security requirements is given in Table 4-6 of the main report.

Using a similar procedure, four levels of physical security protection were also derived for protection against theft and subsequent off-site dispersal. The security measures for protection against on-site sabotage differ somewhat from those for protection against theft (the former protects against intruders with explosives, while the latter protects against unauthorized removal of waste material), and it is possible (and consistent) to require a given facility to have one level of protection against on-site sabotage and a different level of protection against theft. Table ES-1 lists the level of protection requirements recommended for repositories with different site locations and waste types.

---

* An assumption made here was that nuclear reactor saboteurs could cause a release comparable to that of a category 1 accident.

STEP 1 - DETERMINE LEVEL OF PROTECTION VERSUS LEVEL OF CONSEQUENCES FOR EXISTING NUCLEAR FACILITIES/MATERIALS BASED ON CURRENT NRC POLICY. CONSIDER

- CATEGORY II AND III SNM
- SPENT FUEL TRANSPORTATION
- AFR SPENT FUEL STORAGE FACILITIES
- POWER REACTORS

STEP 2 - DETERMINE LEVEL OF PROTECTION VERSUS LEVEL OF CONSEQUENCES FOR HLW REPOSITORIES WHICH IS CONSISTENT WITH CURRENT NRC POLICY. CONSIDER

- DIFFERENT WASTE TYPES
- DIFFERENT REPOSITORY SITE LOCATIONS
- DIFFERENT ADVERSARY ACTIONS

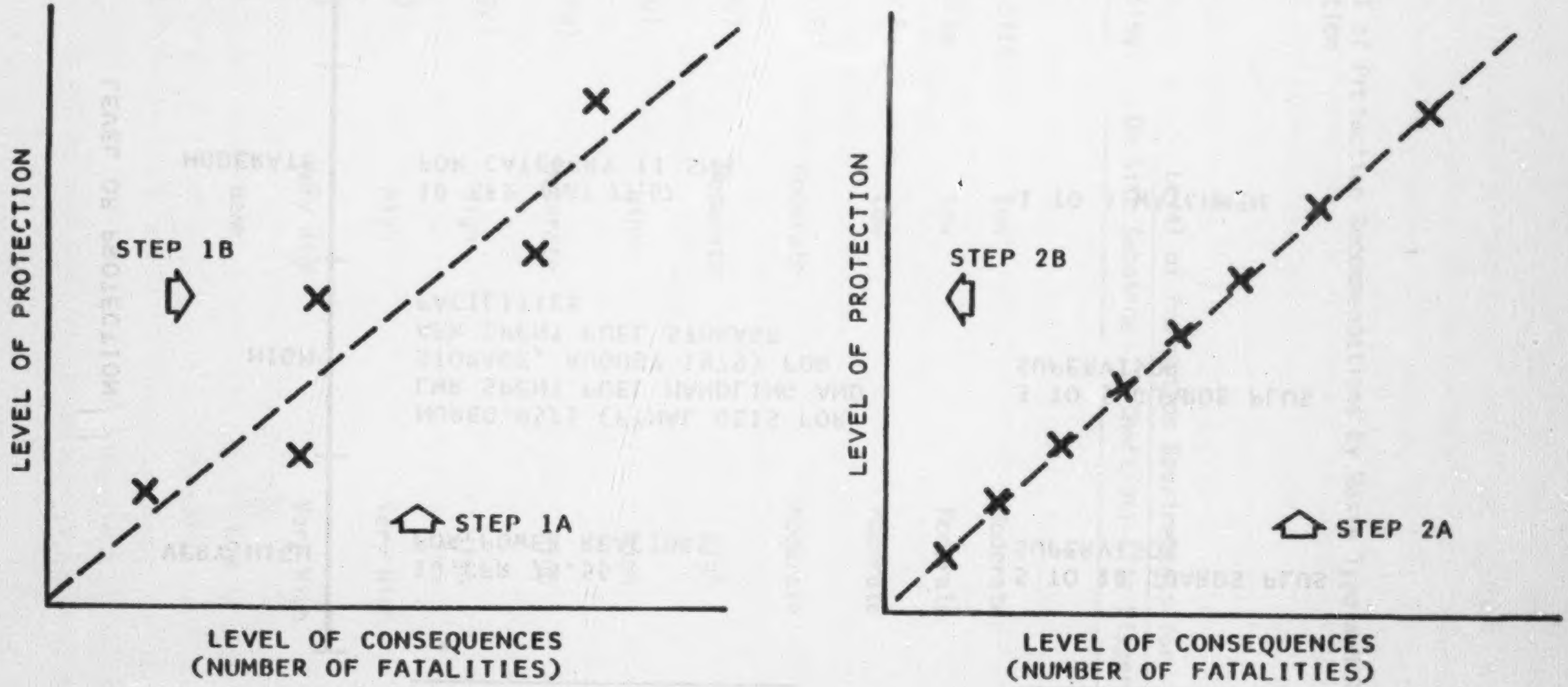


Figure ES-1. Approach for Determining Safeguards Requirements for HLW Repositories.

LEVEL OF PROTECTION	SAFEGUARDS REQUIREMENTS SIMILAR TO THOSE FROM -	EXAMPLE SECURITY MEASURE: SECURITY FORCE/SHIFT -
VERY HIGH	10 CFR 73.55 FOR POWER REACTORS	5 TO 10 GUARDS PLUS SUPERVISOR
HIGH	NUREG-0575 (FINAL GEIS FOR LWR SPENT FUEL HANDLING AND STORAGE, AUGUST 1979) FOR AFR SPENT FUEL STORAGE FACILITIES	3 TO 5 GUARDS PLUS SUPERVISOR
MODERATE	10 CFR PART 73.67 FOR CATEGORY II SNM	1 TO 3 WATCHMEN
LOW	10 CFR PART 73.67 FOR CATEGORY III SNM	0 TO 1 WATCHMAN

Figure ES-2. Level-of-Protection Definitions.

Table ES-1. Level of Protection Recommendations by Waste Type and Repository Location

Waste Type and Siting	Level of Protection Requirements for On-Site Sabotage	 Theft/Off-site Dispersal
Spent Fuel Remote Site	Low	Moderate
Spent Fuel Rural Site	Low	Moderate
Vitrified HLW (w/o Pu) Remote Site	Low	Moderate
Vitrified HLW (w/o Pu) Rural Site	Moderate	Moderate
Vitrified HLW (w Pu) Remote Site	Moderate	High
Vitrified HLW (w Pu) Rural Site	High	High
Calcined HLW (w/o Pu) Remote Site	Moderate	High
Calcined HLW (w/o Pu) Rural Site	High	High
Calcined HLW (w Pu) Remote Site	High	Very High
Calcined HLW (w Pu) Rural Site	Very High	Very High
ILW and LLW	None	Low

Because the above approach involved the use of calculated consequences, it is appropriate to address the effects of consequence uncertainties on this approach. The uncertainties in the consequences for waste repository sabotage were estimated to be about a factor of fifteen, based on propagation of error for the various component parts of the consequence calculations. The consequence uncertainties for the comparative events (sabotage of power reactors, AFR spent-fuel storage, spent-fuel transportation, or Category II or III SNM) were not published in the source literature, but are probably of a similar magnitude since the same general calculational approach and data were used in their analysis.

Because, however, this approach to the derivation of level-of-protection requirements was based on a comparison of consequence results, the relative, not absolute, uncertainties are important. The relative uncertainties are not known, but are expected to be significantly less than the absolute uncertainty because of the use of the same or similar calculation methods and data. The relative uncertainties are expected to be less than a factor of ten. This is within the resolution of the level-of-protection structure derived.

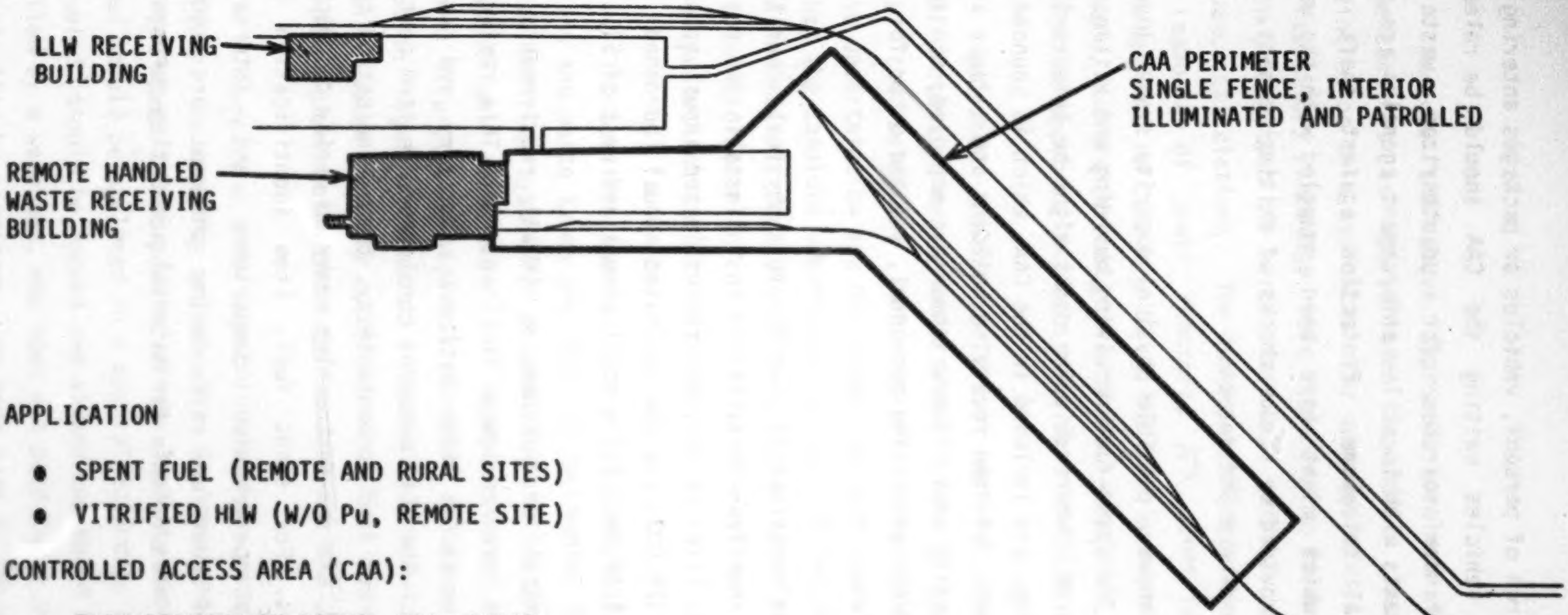
The specific physical security measures for all repository site locations and waste types are detailed in Chapter 4; the major features of a physical security system for a spent-fuel repository are summarized below. The spent-fuel repository for both remote and rural locations requires a low-level of protection against on-site sabotage and moderate level of protection against theft. The requirements are the same for a remotely-located facility accepting vitrified HLW without plutonium, so the description given below also applies to that facility.

There are only a few security requirements for a spent-fuel repository. No security organization is required, but there must be a security plan. That portion of the facility where spent fuel is stored or handled should be enclosed in a controlled access area (CAA), which, when unoccupied, should be locked and either monitored with alarms or be randomly patrolled by a watchman, who does not need to be armed. Access to the CAA is controlled by operators, who have keys to the gates and doors. There is no requirement for search of persons, vehicles or packages entering the CAA, but waste transport vehicles exiting the CAA should be released by a watchman who makes random searches for unauthorized waste cargo. Communication requirements with local law enforcement agencies are satisfied by ordinary commercial telephone. Protection against theft of small quantities of SNM, which might have been smuggled with the waste from another facility, is provided by random checks of exiting persons, packages and vehicles with a hand-held SNM detector.

Figure ES-3 shows a possible physical security system layout for a spent-fuel facility. The spent-fuel receiving building and railroad siding and truck parking area, where shipping casks might be temporarily stored while awaiting unloading, are included in the CAA, which is bounded by the walls and locked doors of the receiving building and a fence around the parking and railroad siding area. Two watchmen are employed, one for random patrol and random checks of exiting personnel, and the other for releasing waste transport vehicles.

The estimated installation cost for this physical security system is $370,000. The annualized installation cost (installation cost of each item amortized over its life) is $37,000; the estimated annual operating and maintenance cost is $24,000, and the estimated annual (burdened) salary of security personnel is $250,000, for a total annualized cost of $311,000.

Material control and accounting (MC&A) requirements for the different waste types are reviewed in Chapter 6. This review is based mainly on recent studies at Oak Ridge National Laboratory and Los Alamos Scientific Laboratory. The MC&A measures considered are item control based on item identification and item accountability, tamper indication to detect loss during shipment, and non-destructive assay to verify the declared SNM contents of waste items. For spent fuel, item identification and item accountability (for shipper-receiver comparisons and internal item control) and sealing of spent-fuel casks during shipment are recommended. Non-destructive assay measurements for material accounting purposes are not recommended.


LLW RECEIVING BUILDING
REMOTE HANDLED WASTE RECEIVING BUILDING
CAA PERIMETER SINGLE FENCE, INTERIOR ILLUMINATED AND PATROLLED

APPLICATION

- SPENT FUEL (REMOTE AND RURAL SITES)
- VITRIFIED HLW (W/O Pu, REMOTE SITE)

CONTROLLED ACCESS AREA (CAA):

- TWO WATCHMEN ON PATROL EACH SHIFT
- LOCKS AND KEYS CONTROLLED BY OPERATORS

SECURITY SYSTEM COSTS:

- TOTAL ANNUALIZED COSTS - $311,000

Figure ES-3. Possible Layout of a Spent Fuel Repository.

The applicability of current NRC rules in 10CFR Part 70 and 73 to the licensing of a HLW repository are reviewed in Chapter 7. Several areas where rule changes are recommended are identified. Alternative safeguards performance capabilities which might be useful for formulating future safeguards rules are discussed.

1. INTRODUCTION

One aspect of the nuclear fuel cycle which has recently been receiving increased attention is the long-term disposition of high-level waste. This is understandable because of the importance in closing the fuel cycle as well as in disposing of the approximately 350 reference reactor years* worth of defense and commercial high-level waste already generated.

The Nuclear Regulatory Commission (NRC) is responsible for developing regulatory requirements and licensing criteria for defense and commercial high-level waste management activities. In addition to accidental occurences which might impact the public, the NRC is concerned with the malevolent perpetration of harmful acts at a high-level waste repository, specifically radiological sabotage or theft of nuclear material for dispersal off-site or for building a weapon.

This report describes the results of a study performed for the NRC to define potential high-level waste repository security requirements to protect against the above malevolent acts. The study results, described herein, cover three efforts. First, analyses were performed to assess the need for high-level waste repository protection. The major areas addressed were on-site and off-site radiological sabotage; however, the difficulties and potential consequences of illegal nuclear weapon production from high-level waste repository materials were also considered. Second, a set of proposed security requirements for protection against the various malevolent acts were developed. These requirements were found to vary depending on the of waste stored as well as on the repository location. Third, a representative security protection system was designed, and the costs of the security system were estimated.

---

* A reference reactor-year has been defined as a 1000 MW(e) reactor operating at 80% capacity for one year.

Figure 1-1 depicts the scope of safeguard concerns for the HLW repository. The major emphasis is on-site dispersal, and to a lesser extent, theft. These concerns are factored into the safeguards system design, which is discussed in Chapters 4 and 5.

The results were found to strongly depend on the type of nuclear waste. Since the light water reactor fuel cycle to be used in the future has not been defined, all the major options were considered. This included once-through, uranium only recycle, and uranium-plutonium recycle. In the once-through fuel cycle, only the unprocessed spent fuel (SF) and certain low level wastes (LLW) are buried. For uranium and plutonium recycle, the wastes include high level waste (HLW), fuel element cladding hulls and fuel assembly hardware, other intermediate level waste (ILW) and LLW. The wastes for uranium only recycle are the same as wastes for uranium-plutonium recycle except for the possible addition of plutonium as a waste. For uranium only recycle, plutonium is assumed either to be included with the HLW, or to be stored at a site other than the HLW repository. This assumption is very important from a security standpoint due to the security implications of high purity SSNM storage.

This report is organized as follows: This introduction, Chapter 1, is followed by a short description of geologic HLW repositories in Chapter 2. Chapter 3 summarizes the approach, method of analysis, results and caveats of the consequence analyses. Chapter 4 describes the approach, data and results of the security system requirements definition. Chapter 5 describes the example repository security system designs and estimated costs. Material control and accounting requirements are reviewed in Chapter 6. Regulatory impacts, including the applicability of current NRC rules, are discussed in Chapter 7.

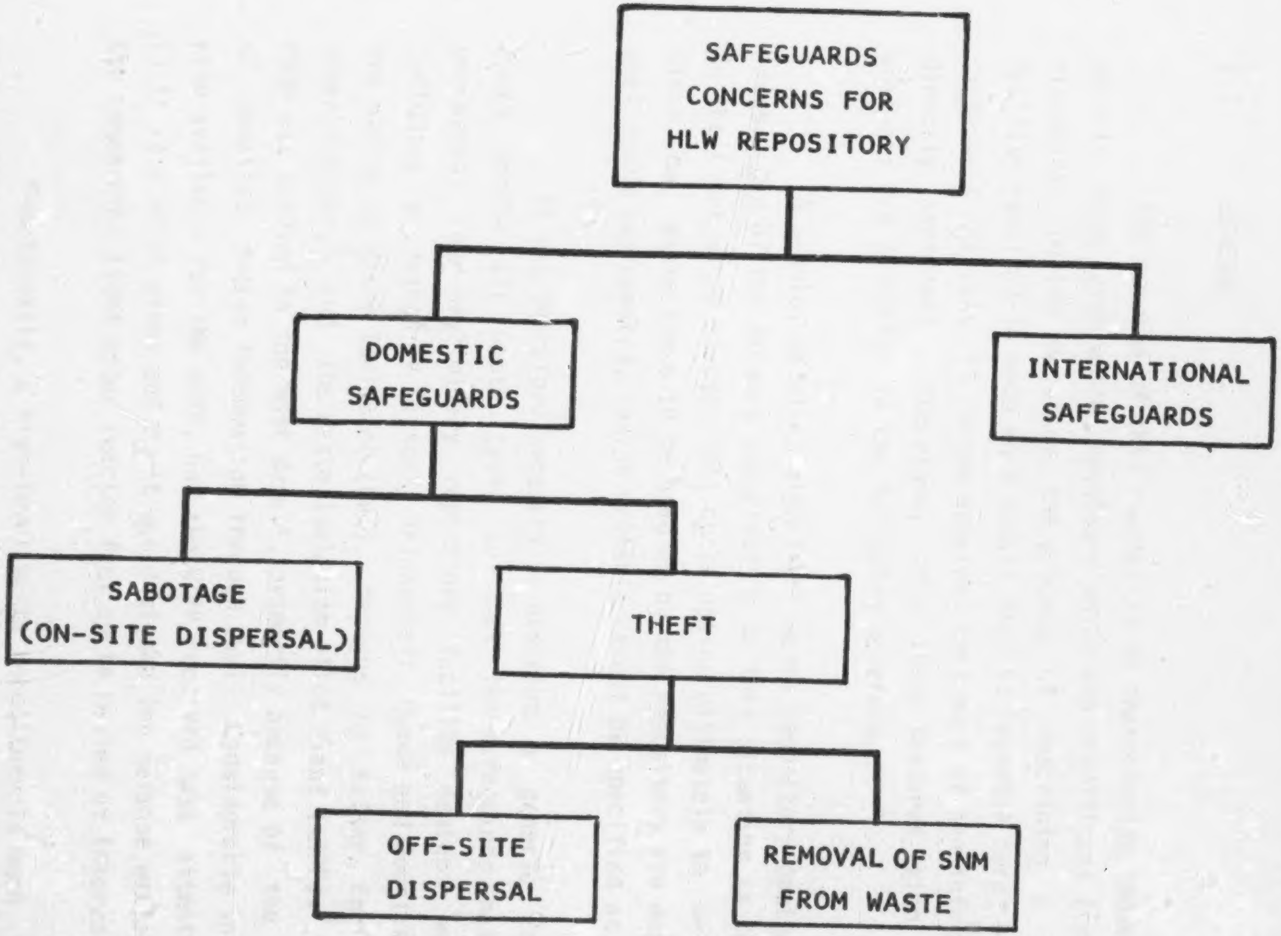

SAFEGUARDS CONCERNS FOR HLW REPOSITORY
DOMESTIC SAFEGUARDS
INTERNATIONAL SAFEGUARDS
SABOTAGE (ON-SITE DISPERSAL)
THEFT
OFF-SITE DISPERSAL
REMOVAL OF SNM FROM WASTE

Figure 1-1. Scope of safeguards concerns.

Figure 1-2 depicts the scope of [illegible] for the HLW repository. The major emphasis is [illegible], and to a lesser extent, [illegible]. These [illegible] from the [illegible] system design, which is discussed in Chapters 4 and 5.

[illegible]

[illegible]

2. HIGH LEVEL WASTE REPOSITORY DESCRIPTION

2.1 GENERAL

The purpose of this chapter is to characterize those features of a generic high-level waste repository which are significant from a safeguards viewpoint. During the study, the process of describing a representative facility resulted in much more detail than is reported here; however, in the subsequent analysis, it became apparent that much of the information was not directly pertinent. Therefore, only those features which figured in the analysis are described in the following sections.

A single, detailed high-level waste repository design does not yet exist. One of the factors contributing to this situation is the uncertainty in the light water reactor fuel cycle option ultimately to be implemented. Since the waste types to be handled by the repository are dependent on the fuel cycle implemented, design criteria cannot be specified at this time.

It was therefore necesary to describe a generic facility which could handle all waste types so that the safeguards analysis could be performed. Four preliminary repository facility designs were reviewed, including a design by Parsons, Brinkerhoff, Quade and Douglass (PBQD)[1] for the Office of Waste Isolation (OWI), designs by Kaiser Engineering[2] and Stearns-Roger,[3] and the Waste Isolation Pilot Plant (WIPP).[4] The design by PBQD was studied in the most detail, primarily because of the availability of detailed design information through ONWI. Considerable information was also available for the WIPP, but the WIPP received less attention because, 1) it is a pilot plant and 2) it was designed for defense wastes rather than the commercial light water reactor fuel cycle wastes of interest here.

Functionally, a high-level waste repository is much simpler than most other nuclear facilities, especially nuclear reactors and fuel reprocessing facilities, and has several inherent features which aid facility security. One such feature is the containment afforded by the thick shielding walls of the high-level and intermediate-level waste handling areas, both above ground and at the mine level. Another such feature is the typical one-way flow of nuclear materials in the facility. This would tend to severely complicate the covert removal of emplaced material by an adversary.

An artist's concept of a geologic high-level waste repository, taken from Reference 5, is shown in Figure 2-1. The repository consists of a number of waste disposal chambers deep (typically about 2000 ft) below the surface, together with access shafts and supporting facilities. The underground facility occupies an area of approximately 2000 acres, while the surface facility, not including mined material storage, occupies about 200 acres. The underground facility may include chambers at two separate levels, with one level for LLW transuranic (TRU) wastes and another for the remote handled high-level wastes. During operation of the repository, both mining and emplacement activities take place. It is expected that there will be a time period of a few months to several years between the time of chamber excavation and placement of the wastes.

There will be several access shafts to provide (1) access of men and working materials to the mining and waste emplacement areas, (2) removal of mined materials, (3) ventilation supply, (4) ventilation exhaust, (5) transfer of LLW and (6) transfer of RH canisters. In the various designs, certain of these functions may be combined in a single access shaft. For example, in the PBQD concept of Figure 2-1, the men and materials (M&M) access and mined materials removal functions both take place in the M&M shaft, while in the WIPP design, the M&M shaft is used for both these functions plus ventilation supply.[6]

The surface facilities accommodate frequent delivery of wastes by either truck or rail. There are typically two waste receiving and handling buildings, one for contact-handled LLW and another for remote-handled waste (spent fuel, or HLW or ILW, see Table 2-1). Other surface buildings house facilities of lesser interest. These include ventilation supply and exhaust, administration, emergency power, cafeteria, and others.

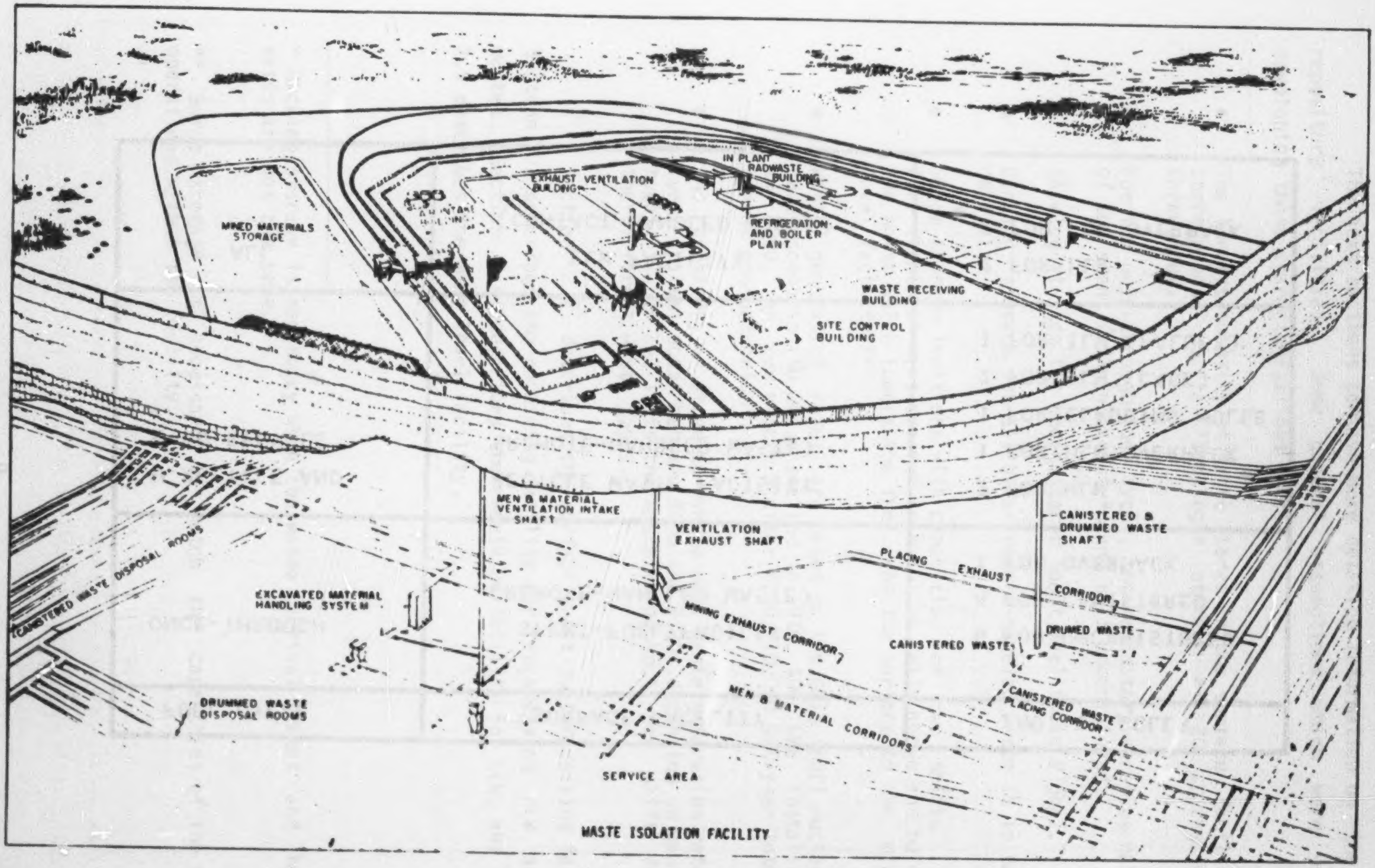

MIXED MATERIALS STORAGE
AIR INTAKE BUILDING
EXHAUST VENTILATION BUILDING
IN PLANT RADWASTE BUILDING
REFRIGERATION AND BOILER PLANT
WASTE RECEIVING BUILDING
SITE CONTROL BUILDING
MEN & MATERIAL VENTILATION INTAKE SHAFT
VENTILATION EXHAUST SHAFT
CANISTERED & DRUMMED WASTE SHAFT
PLACING EXHAUST CORRIDOR
DRUMED WASTE
CANISTERED WASTE
CANISTERED WASTE DISPOSAL ROOMS
EXCAVATED MATERIAL HANDLING SYSTEM
MINING EXHAUST CORRIDOR
MEN & MATERIAL CORRIDORS
CANISTERED WASTE PLACING CORRIDOR
DRUMMED WASTE DISPOSAL ROOMS
SERVICE AREA
WASTE ISOLATION FACILITY

Figure 2-1. Artist's Concept of High Level Waste Repository.

Table 2-1. Surface Facilities for Handling Waste.

FUEL CYCLE	SURFACE FACILITY	NO. OF CELLS
ONCE-THROUGH	SPENT-FUEL FACILITY (REMOTE-HANDLED WASTE)	6 FOR UNCANISTERED 4 FOR CANISTERED 1 FOR OVERPACK
U RECYCLE AND U-PU RECYCLE	RECYCLE WASTE FACILITY (REMOTE-HANDLED WASTE)	2 FOR HLW 1 FOR HLW OVERPACK 1 FOR CLADDING HULLS 2 FOR ILW (CASK) 1 FOR ILW (PALLET)
ALL	LLW FACILITY (CONTACT-HANDLED WASTE)	2 FOR LLW 1 FOR LLW OVERPACK

The next sections contain more detailed information on the major repository facilities. Some general assumptions which were used in developing these characterizations are:

- The largest quantity of waste stored in the surface facility corresponds to a "backlog"* storage of 20 shifts of throughput.
- For the once-through fuel cycle, the repository receives half of the spent fuel in canisters and half uncanistered.
- Backlog storage for uncanistered spent fuel is in a pool.
- Backlog storage for all other remote-handled waste is in hot cells.
- Surge storage locations with capacities for two shifts (25 fuel elements) were assumed to exist in cells above and below the hoist which lowers the fuel from the surface to the mine level facility.**
- Waste generation rates are based on the GEIS (ref) nuclear power scenario (50 GWE installed in 1979, 400 GWE installed in 2000, no new reactors after 2000, 10,000 GWE-year total energy production).
- The repository is sized to handle peak waste generation rates (peak rates occur between 2005 and 2020, depending on waste type). Table 2-2 lists the waste throughput per shift for the different waste types.

Section 2.2 describes the surface spent-fuel receiving facility, Section 2.3 describes the receiving facility for reprocessing HLW and ILW wastes, Section 2.4 describes the receiving facility for LLW, and Section 2.5 describes the mine level facility.

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* Backlog storage is necessary when the waste arrival rates and handling rates are not the same.

** Surge storage is necessary to match the capacities of the various operations within the facility.

Table 2-2. Number of Waste Containers.

WASTE TYPE	NUMBER OF CONTAINERS			
	MAXIMUM LOAD PER INCOMING VEHICLE	THROUGHPUT PER SHIFT	BACKLOG STORAGE	
			TOTAL	CELL
SPENT FUEL				
UNCANISTERED PWR	10/CASK	8	160	27
UNCANISTERED BWR	24/CASK	13	260	43
CANISTERED PWR	7/CASK	8	160	40
CANISTERED BWR	17/CASK	13	260	65
HLW				
VITRIFIED (0.3 M DIAM.CAN.)	9/CASK	6	120	60
CALCINED (0.2 M DIAM.CAN.)	20/CASK	6	120	60
CLADDING HULLS	3/CASK	3	60	60
ILW (55-GAL. DRUMS)				
>10 R/HR	6/CASK	27	} 800	} 400
1 - 10 R/HR	14/CASK	13		
0.2 - 1 R/HR	36/VAN	12	240	240
LLW (55-GAL. DRUMS)				
<0.2 R/HR	36/VAN	39	780	780

2.2 SPENT FUEL RECEIVING FACILITY

If the once-through light water reactor fuel cycle is chosen, no fuel reprocessing would occur and spent fuel would be processed in the RH receiving and handling facility. It is not known at this time whether spent fuel received at the facility would be canistered or uncanistered; designs have been developed for both.[1,2,3]

The spent fuel, either canistered or uncanistered, will arrive in rail and/or truck shipping casks. There are a variety of shipping casks, but for purpose of analysis it is assumed that the NLI 10-24 cask is used for rail shipments and that a cask with about a third the NLI 10-24 cask capacity is used for truck shipments. The NLI 10-24 cask capacity is ten uncanistered PWR fuel assemblies or twenty-four uncanistered BWR fuel assemblies. The capacity for a modified NLI 10-24 cask is seven canistered PWR fuel assemblies or seventeen canistered BWR fuel assemblies.

At this point, the handling for canistered versus uncanistered spent-fuel elements differs. These will each be discussed separately in the following subsections.

2.2.1 Canistered Spent Fuel

Upon arrival, the cask and security seals are inspected and the cask is decontaminated if necessary. The cask is then removed from the truck/rail car and transferred to one of several hot cells, where the cask is opened and the fuel assemblies are removed. After removal from the cask, the canisters are inspected and leak tested, washed if contaminated, and transferred to an overpack cell if leaking. Finally, the canisters are transferred to the hoist house, where they are lowered into the mine in baskets of four.

The canistered waste receiving building, shown in Figures 2-2 and 2-3, is a two-story structure constructed of thick reinforced concrete. There are six parallel sets of canistered waste processing cells plus one set of cells with overpack capability for leaking canisters. Each cell is

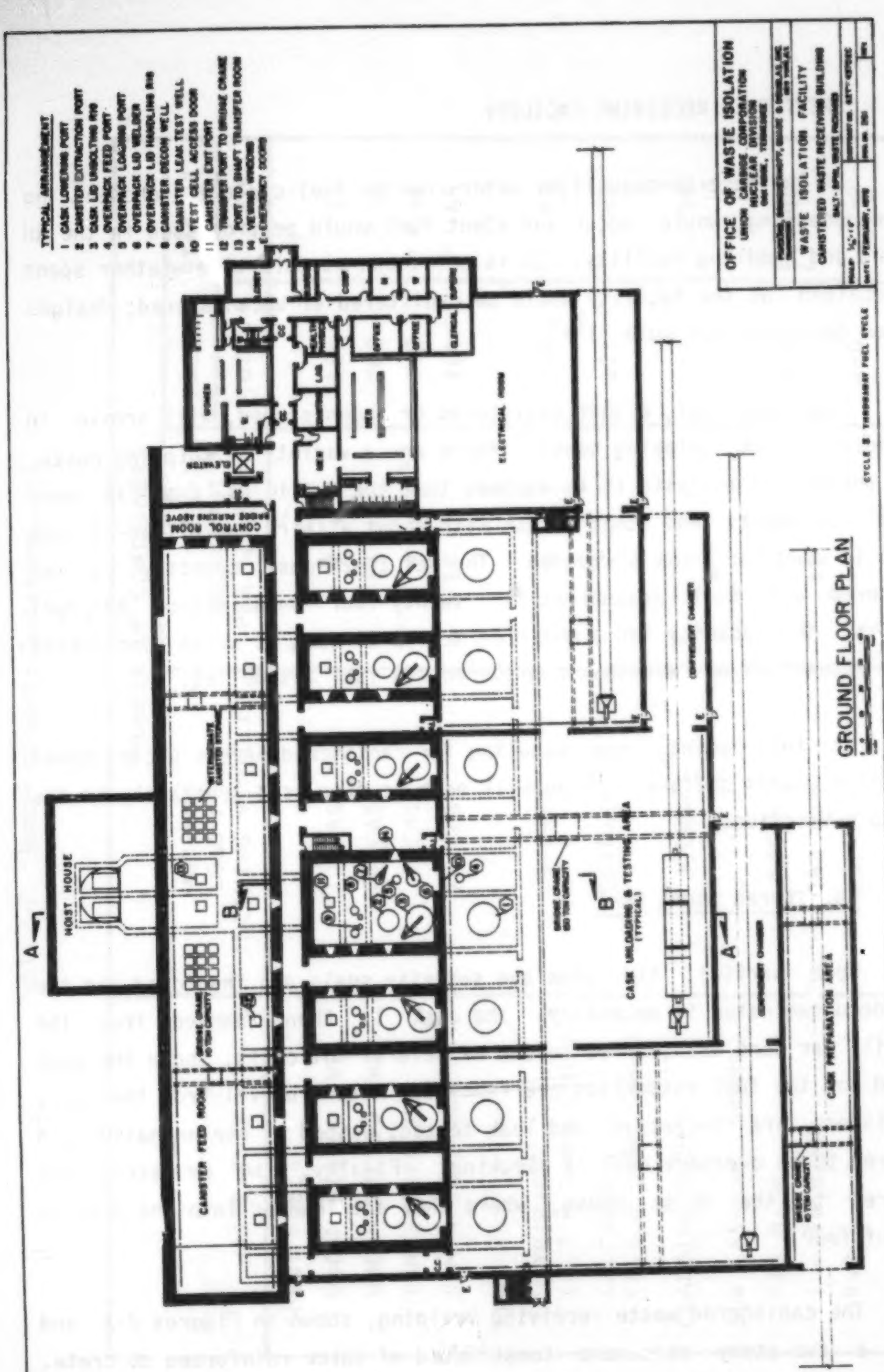

Figure 2-2. Canistered Waste Facility Plan View.

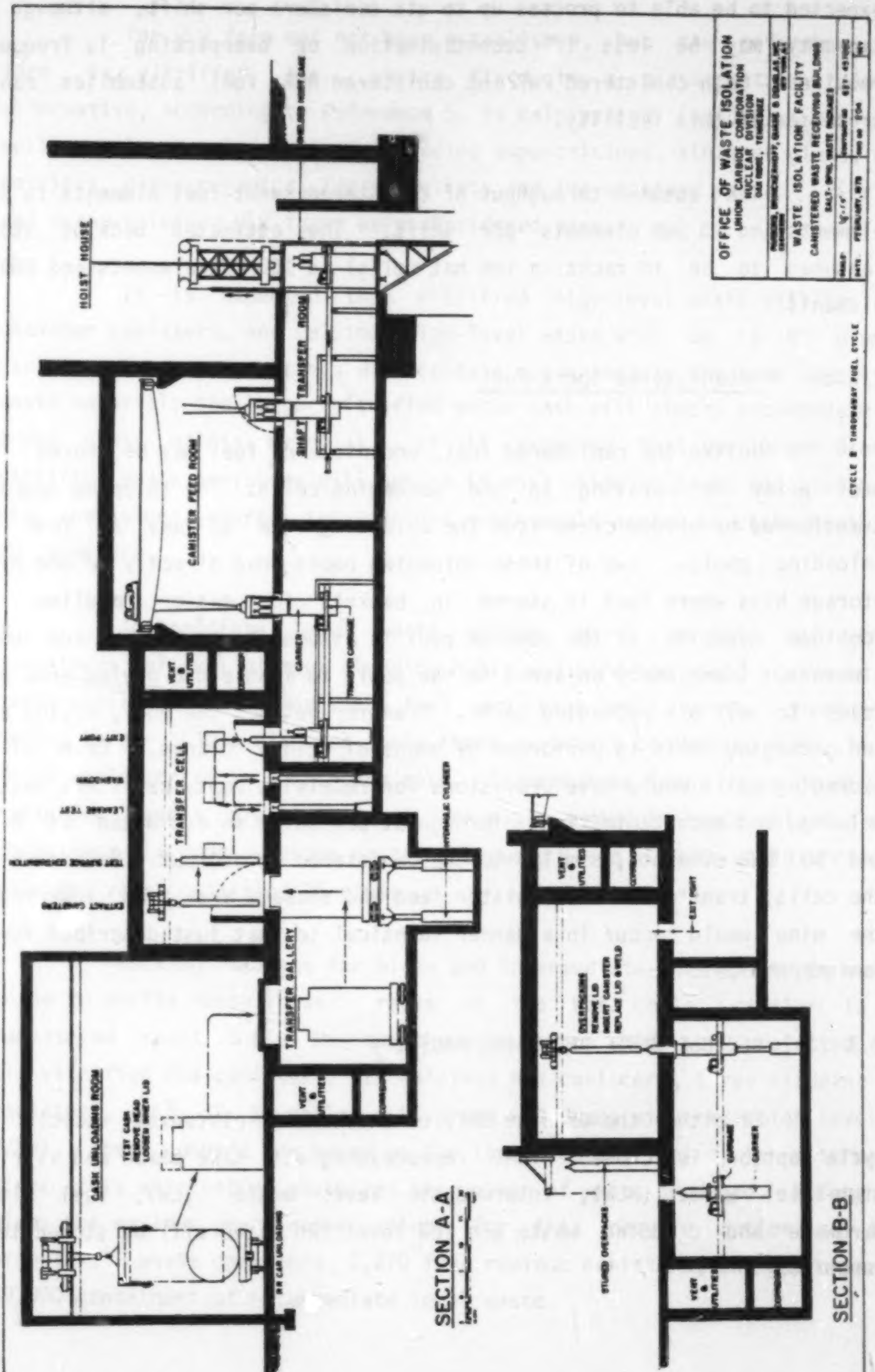

Figure 2-3. Canistered Waste Facility Elevation View.

expected to be able to process up to six canisters per shift, although the capacity may be less if decontamination or overpacking is frequently required. Both canistered PWR and canistered BWR fuel assemblies can be processed in this facility.

The assumed throughput of canistered spent-fuel elements is 8 PWR elements and 13 BWR elements per shift. The estimated backlog storage (assumed to be in racks in the hot cells) is 160 PWR elements and 260 BWR elements.

2.2.2 Uncanistered Spent Fuel

Unlike the canistered fuel, uncanistered fuel may be stored in a pool prior to arriving in the packaging cells. The shipping casks are transferred by bridge crane from the unloading area to any of four cask unloading pools. Two of these unloading pools lead directly to one of two storage bins where fuel is stored in baskets for easier handling. The combined capacity of the storage pool is assumed to be 160 PWR and 260 BWR elements. Immediately adjacent to the pools is a shielded drying area which leads to all six packaging cells. Transfer between the pool, drying area, and packaging cells is performed by means of bridge cranes. Each of the packaging cells would have provisions for receiving empty canisters testing, welding, and decontamination. Throughput per shift is estimated at 8 PWR and 13 BWR elements, similar to the canistered throughput. Unloading from the cells, transfer to the canister feed and storage area, and lowering to the mine would occur in a manner identical to that just described for the canistered fuel.

2.3 RECYCLE WASTE RECEIVING FACILITY

If either the uranium only or the uranium-plutonium recycle fuel cycle option is chosen, fuel reprocessing will take place and vitrified high-level waste (HLW), intermediate level waste (ILW), fuel element hardware and cladding waste and low level TRU waste will be stored in the repository.

The HLW form has not been established, but the reference waste form is vitrified, i.e., wastes fixed in a glass matrix. Another alternative, according to Reference 5, is calcination (oxides), with less well developed alternatives including supercalcined, sintered glass, metal matrices, glass-ceramics, coated pellets and ion exchange media. Vitrified and spray-calcined HLW forms were considered here.

It is expected that vitrified high-level waste will be in 12" diameter canisters, and calcined high-level waste will be in 8" diameter canisters. Both canisters will contain approximately the same quantity of waste material; the larger vitrified waste cask will simply accommodate the added glass matrix material. It is expected that the larger diameter vitrified waste canisters will arrive in rail shipping casks containing only nine canisters, whereas the calcined waste would arrive in casks containing 20 canisters.

Intermediate level waste arrives in a variety of forms. Containers of fuel element cladding hulls and hardware would arrive in rail casks similar to those for spent fuel and high-level waste. Because of their larger (30") diameter, only three canisters containing fuel cladding hulls would arrive in a shipping cask. Intermediate level waste drums with radiation levels greater than 10R/hr would arrive in truck shipping casks containing six drums. Drums emitting between 1 and 10 R/hr would arrive in shielded vans containing 36 drums.

Backlog storage for high- and intermediate-level waste is assumed to be 20 shifts worth in wall racks in the hot cells, similar to the canistered spent fuel. Maximum throughputs per shift were projected to be six vitrified HLW canisters, six calcined HLW canisters, three cladding hull canisters, and 52 55-gallon LLW drums (40 drums with radiation levels >1 R/hr). These numbers are based on the total recycle fuel cycle alternative since this alternative maximizes the volume of waste produced. Reference 5 gives the maximum year waste volume for this recycle option as 4,510 high-level waste canisters, 2,270 fuel residue canisters, and approximately 39,000 containers of intermediate level waste.

The receiving and processing facility for reprocessing wastes would be similar in some respects to the canistered spent-fuel-handling facility described in Section 2.2. There would be several parallel sets of hot cells for unloading and processing the wastes, but because of the different canister and drum sizes and shapes, different sets of these cells would be designed to accommodate the different waste types. For example, two sets of cells might be specialized to handle HLW canisters, one cell for cladding and fuel hardware canisters, and four cells for handling ILW drums. Also, each series of cells would have overpack capability.

Figure 2-4, taken from Reference 1, shows a concept of a set of hot cells for unloading and processing HLW. A similar drawing, not included here, showed an almost identical facility for ILW. The facility and operations are very similar to those discussed earlier for canistered spent fuel: the loaded cask is removed from the truck or rail car and is lowered to a below-grade transfer cell, where the cask lid is removed. The cask then mates with an access port to an upper-level room and the canisters are removed. The canisters are then inspected and tested for leaks and surface contamination. If necessary, the canisters are overpacked or decontaminated, then the canisters are transferred to baskets and the hoist facility.

2.4 LOW LEVEL WASTE RECEIVING FACILITY

The low level waste building at the waste repository handles low level waste generated in the once-through fuel cycle or during reprocessing for the other fuel cycles. Although the amount of TRU-generated low level waste without fuel reprocessing would be quite small, deep storage of non-TRU wastes is possible, and was provided for in the two Nuclear Waste Terminal Storage Facility designs[2,3] performed for DOE in 1978.

Low level waste is packaged in 55-gallon drums, 80-gallon drums, and boxes. Most of these containers would arrive at the facility in truck-carried or rail-carried containers known as "supertigers", which have the capacity for 36 or 42 drums.

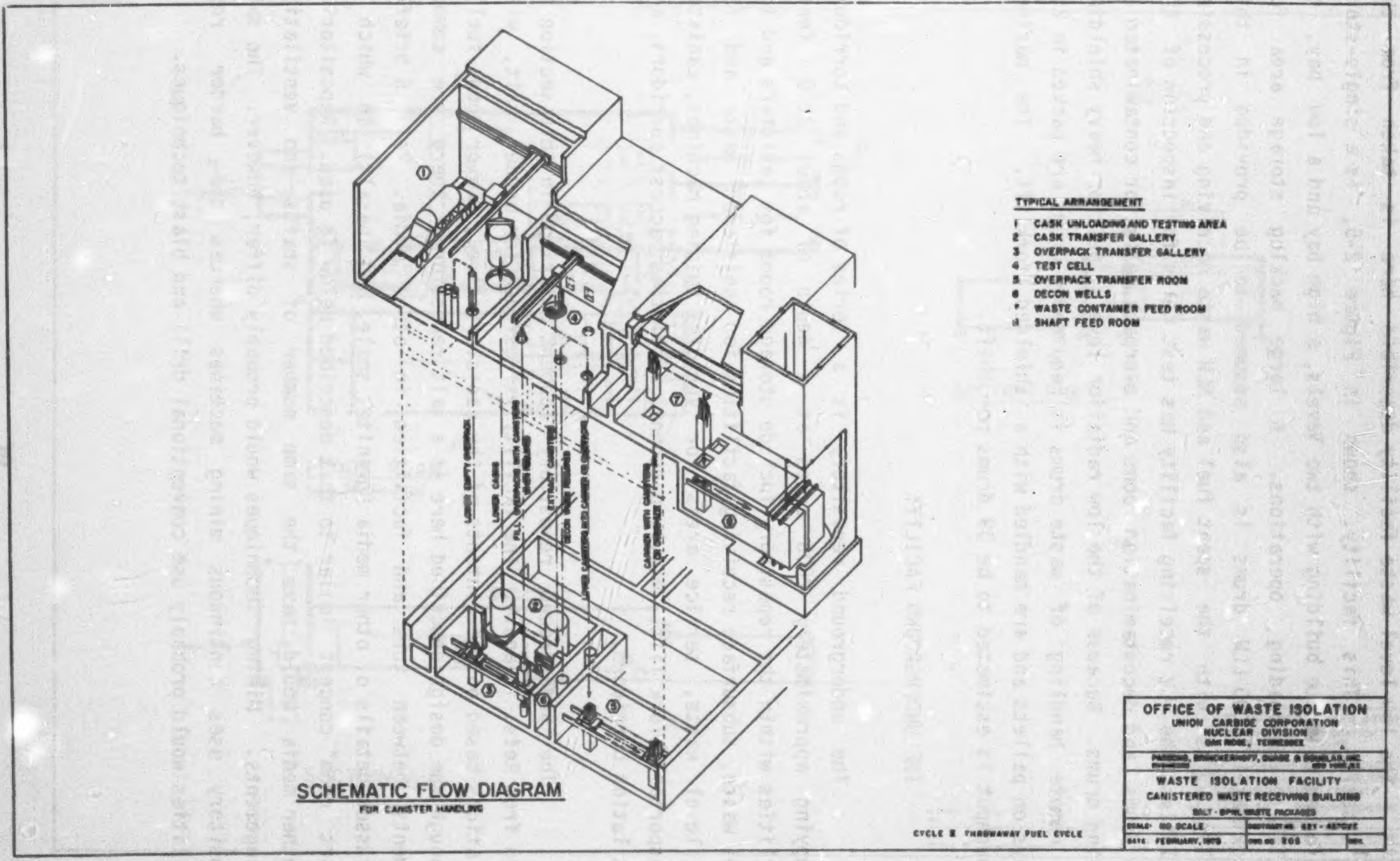

Figure 2-4. HLW Receiving and Processing Facility.

The low level waste facility described here is taken from the PBQD[1] design. This facility, shown in Figure 2-5, is a single-story reinforced concrete building with two levels, a high bay and a low bay, to facilitate unloading operations. A large backlog storage area for approximately 1000 LLW drums is also assumed to be provided in this facility. As with the spent fuel and HLW waste receiving and processing facilities, the LLW receiving facility has test cells for inspection of the LLW drums and decontamination rooms and overpack cells for contaminated or leaking drums. Because of the low radiation levels, neither heavy shielding nor remote handling of waste drums is required. Drums are packed in 2x3 arrays on pallets and are handled with a shielded forklift. The maximum throughput is estimated to be 39 drums per shift.

2.5 THE UNDERGROUND FACILITY

The underground repository is a series of rooms and corridors occupying approximately 2000 acres at a depth of about 2000 feet. Facilities within the repository include storage rooms for canisters and low level waste, subsurface receiving facilities for canistered waste and for low level waste, service areas for vehicles (mining machines, canister transporters, fork lifts, etc.), personnel facilities, access corridors, and ventilation corridors.

The underground repository concept described in this section is taken from Refs. 1 and 4. The facility is designed for bedded salt, with variations based on the contents of the canisters (i.e., HLW or spent fuel). Although the design described here is a salt repository, there are common elements between this and facilities in other media. Ref. 5 briefly discusses details of other media (granite, shale, and basalt) in which a "short room" concept similar to that described below is used. Repositories in other media would have the same number of shafts and ventilation arrangements. Mining techniques would probably differ, however. The salt repository uses continuous mining machines whereas the harder rock facilities would probably use conventional drill and blast techniques.

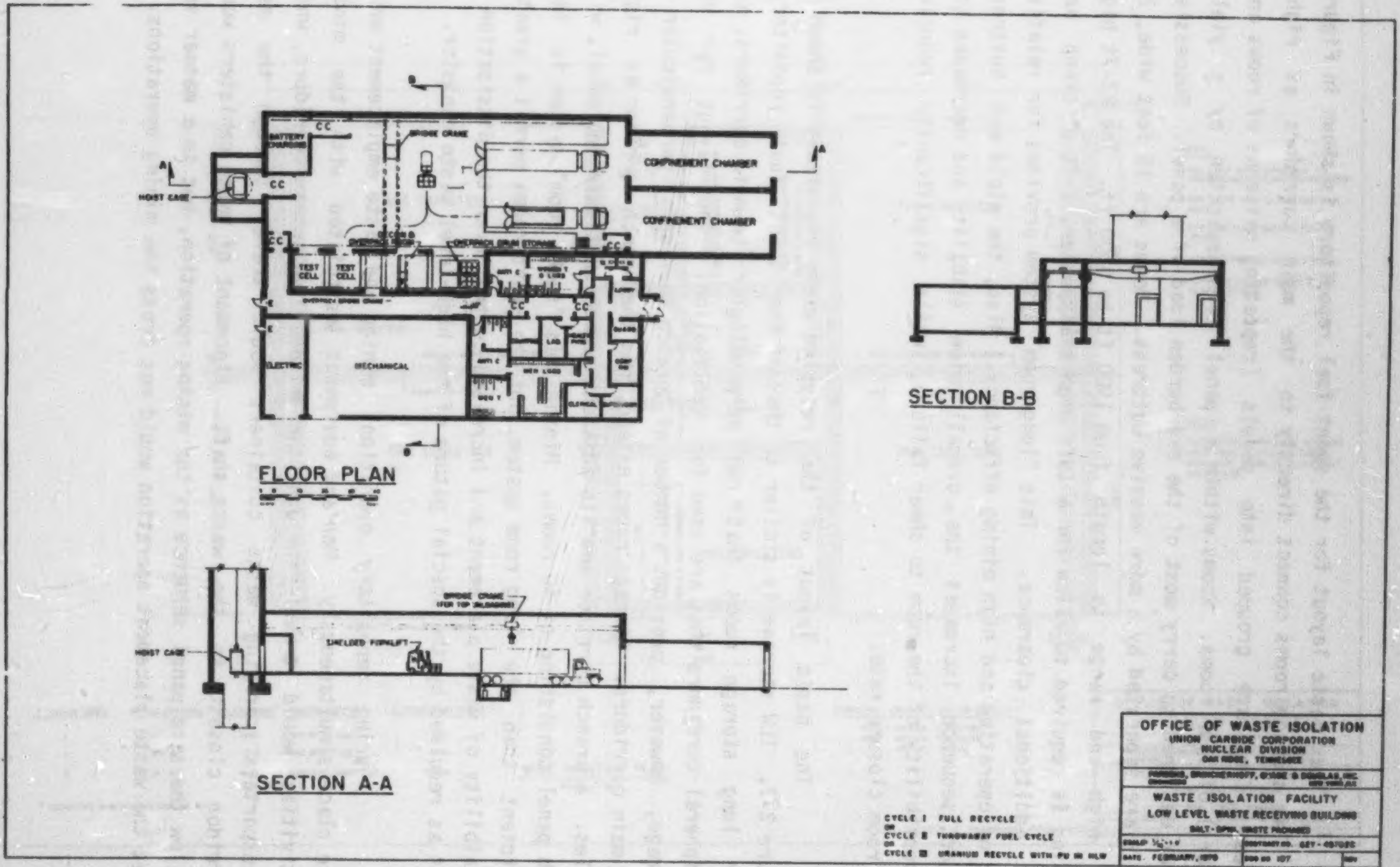

Figure 2-5. Low-Level Waste Receiving Facility.

The basic layout for the spent fuel repository is shown in Figure 2-6. The storage rooms connect directly to the main corridors at right angles. They are grouped into panels (repeating patterns of rooms and pillars) of four rooms. Rooms within a panel are separated by a yield pillar designed to carry most of the overburden load of a panel. Successive panels are separated by a more massive buttress. Rooms are 18 feet wide, 22 feet high and range in length from 1900 ft to 3500 ft. The 22-ft high ceiling is required to allow for a 19ft high transporter, 2-ft of creep and 1-ft additional clearance. This "long room" system provides for relative ease of operation and high mining efficiency. Also, the yield and buttress pillar sequence increases the overall mine stability and decreases the susceptibility of the room to shear failure, while significantly reducing the room closure rate.

The basic layout of the recycled waste repository is shown in Figure 2-7. ILW storage is similar to that of the spent fuel repository, with long storage rooms that run perpendicular to main corridors, and peripheral corridors that are used for ventilation. The layout for HLW storage, however, provides a number of "branch corridors" perpendicular to the main corridors. Storage rooms extend from the branch corridor at right angles. A branch corridor and its adjacent rooms constitute one panel, with each panel consisting of 40 rooms. Mining this "short room" system is less efficient than the long room system, but the short rooms permit a greater flexibility of waste placement and increased control over the dissipation of heat as required by the special nature of the high-level waste canister.

During repository operation, mining and waste emplacement would take place simultaneously. Men and equipment associated with the mining activities would travel through the middle two access corridors, while transporters carrying waste containers would travel through the main corridor closest to the waste shaft. Placement of waste canisters would follow the same panel sequence as the mining operation, but in a manner such that the waste placement operation would not cross the mining operations.

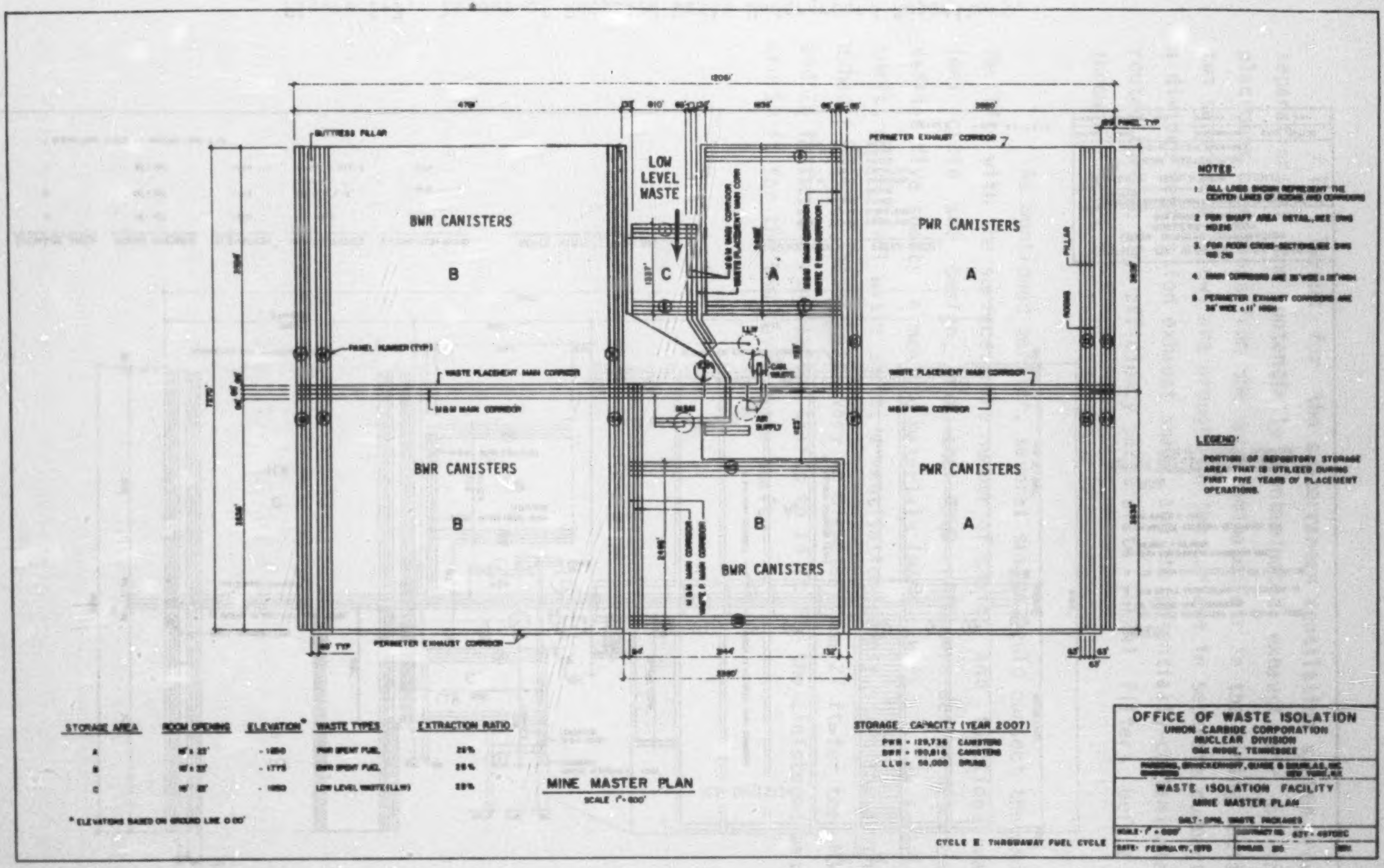
BWR CANISTERS
B
PWR CANISTERS
A
LOW LEVEL WASTE
C
BUTTRESS PILLAR
PANEL NUMBER (TYP)
WASTE PLACEMENT MAIN CORRIDOR
M&M MAIN CORRIDOR
PERIMETER EXHAUST CORRIDOR
PILLAR
ROOMS
LLW
AIR SUPPLY
NOTES:
1. ALL LINES SHOWN REPRESENT THE CENTER LINES OF ROOMS AND CORRIDORS
2. FOR SHAFT AREA DETAIL, SEE DWG NO.216
3. FOR ROOM CROSS-SECTIONS, SEE DWG NO.218
4. MAIN CORRIDORS ARE 30' WIDE x 22' HIGH
5. PERIMETER EXHAUST CORRIDORS ARE 24' WIDE x 11' HIGH
LEGEND:
PORTION OF REPOSITORY STORAGE AREA THAT IS UTILIZED DURING FIRST FIVE YEARS OF PLACEMENT OPERATIONS.
STORAGE AREA
ROOM OPENING
ELEVATION*
WASTE TYPES
EXTRACTION RATIO
A
- 1850
PWR SPENT FUEL
25%
B
- 1775
BWR SPENT FUEL
25%
C
- 1850
LOW LEVEL WASTE (LLW)
25%
* ELEVATIONS BASED ON GROUND LINE 0.00'
MINE MASTER PLAN
STORAGE CAPACITY (YEAR 2007)
PWR - 129,736 CANISTERS
BWR - 190,816 CANISTERS
LLW - 50,000 DRUMS
CYCLE II THROWAWAY FUEL CYCLE
OFFICE OF WASTE ISOLATION
UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE
WASTE ISOLATION FACILITY
MINE MASTER PLAN
DATE: FEBRUARY, 1978

Figure 2-6. Layout of Spent Fuel Underground Repository.

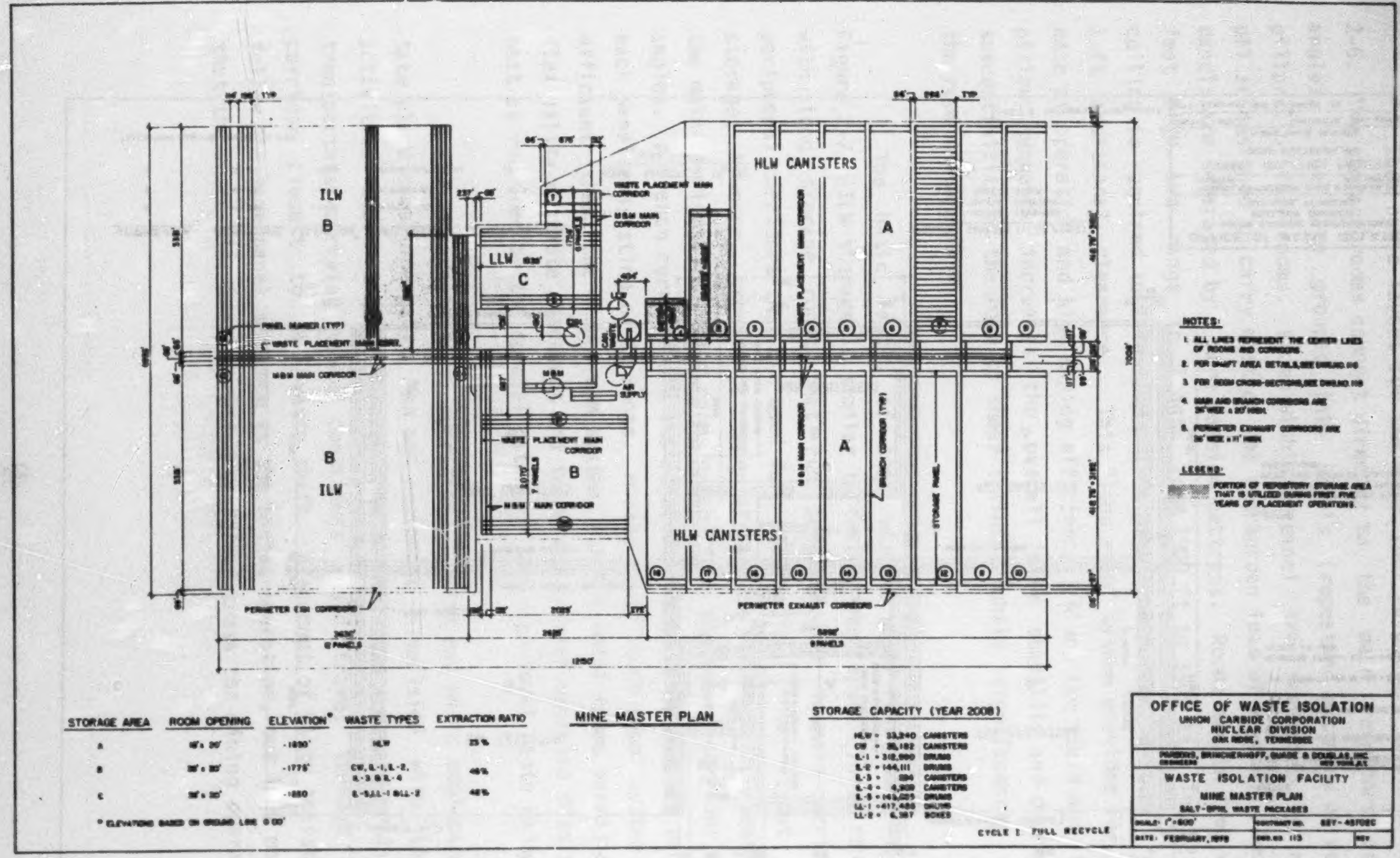

Figure 2-7. Layout of Recycled Waste Underground Repository.

The layout for the subterranean ventilation system provides for separation of the potentially contaminated exhaust air of the waste placement operations from the uncontaminated air in the mining section. The two separate airflows are brought to the surface in separate compartments of a divided ventilation exhaust shaft, and the potentially-contaminated air is routed through high efficiency particulate (HEPA) filters before release through a stack.

As mentioned earlier, several shafts would connect the underground facility with the surface. The number of shafts and functions vary with fuel cycle and design, but the PBQD reference design described herein defined five shafts: a men and materials (M&M) shaft, a canistered waste shaft, a low level waste shaft, a ventilation supply shaft and a ventilation exhaust shaft. These shafts vary in diameter from 27 ft for the M&M shaft and 26 ft for the ventilation shafts to 14 ft for the canistered waste shaft and 10 ft for the low level waste shaft.

The layout for the subterranean ventilation system provides for separation of the potentially contaminated exhaust air of the waste placement operations from the uncontaminated air in the mining section. The two exhaust air flows are brought to the surface in separate compartments of a divided ventilation exhaust shaft, and the potentially-contaminated air is routed through high efficiency particulate (HEPA) filters before release through a stack.

As mentioned earlier, several shafts would connect the underground facility with the surface. The number of shafts and functions vary with fuel cycle and design, but the ONWI reference design described herein defines five shafts: a men and materials (M&M) shaft, a canistered waste shaft, a uncanistered waste shaft, a ventilation supply shaft, and a ventilation exhaust shaft. Shaft diameters vary in diameter from 27 ft for the M&M shaft and 24 ft for the ventilation shafts to 14 ft for the canistered waste shaft and 18 ft for the uncanistered waste shaft.

3. RADIOLOGICAL CONSEQUENCE ANALYSIS

3.1 GENERAL

The consequences of radiological sabotage of a high-level waste facility were estimated for two reasons, first to establish the need for a security system to protect against radiological sabotage, and second to provide a basis for the level of security required. Two forms of radiological sabotage were of interest, on-site sabotage, which could take place in the receiving yard, in a surface building or at the mine level, or off-site sabotage, which would involve theft of waste material with dispersal at an off-site location. While a theft/sabotage event could result in an off-site dispersal almost anywhere, it was assumed, for purposes of consequence analysis, that the dispersal occurred in a densely populated urban area.

An attempt was made to perform reasonable (not worst case) analyses of severe (but again not worst case) sabotage events. This did not prove to be easy because of the choices that had to be made in case selection and the many uncertainties involved in the calculations. Also, there was a tendency to prefer to overestimate, rather than to risk underestimating, the consequences. As a result, it is expected that the consequence results reported are much higher than would actually occur if the sabotage events analyzed herein were to happen, and many times, in fact, worst case results were developed and/or used.

It is appropriate to address consequence analysis uncertainties before continuing. Every step in the consequence analysis procedure is subject to uncertainties, some of which are large. Two of the largest areas of uncertainty are the release fraction of radioactive material and the atmospheric transport. The uncertainties for these two factors are not known, but potentially span several orders of magnitude. The approach in dealing with these uncertain areas was to use, where available, standard, or at least existing, methods of analysis. The source term, for example, for shipping cask sabotage was based on release fractions estimated by Sandia in their recent urban fuel element transport analysis,[7] and the atmospheric transport was evaluated using standard Gaussian plume methods. The authors believe that the consequence results reported herein should be updated when better release data became available.

This chapter is divided into five sections. In Section 3.2, the selection of sabotage events to be analyzed and the required adversary sabotage actions are discussed. In Section 3-3, the waste container contents and release fractions estimated for the reference sabotage events are described. Section 3.4 describes the data and method of analysis used for the calculation of consequence effects, including pathways, dose factors, and health risk estimates. Last, Section 3.5 presents the calculated consequence results and discusses some of the uncertainties.

3.2 SELECTION OF REFERENCE SABOTAGE EVENTS

The reference sabotage events, selected for detailed consequence analysis, were derived in a two-step process involving first the derivation of candidate sabotage possibilities, and second, a screening process to choose the reference events from the larger list of possibilities.

Sabotage possibilities are characterized by a location in the repository and by a release mechanism. The locations in the facility which are candidates for sabotage are termed targets, and involve a particular waste type and waste inventory. Release mechanisms fall into two general categories, generic mechanisms, which are considered for each target and include fire, explosion, and mechanical impact, and target specific mechanisms such as a hoist drop event or a shaped charge attack on a cask. Specific mechanisms include those possibilities which are suggested by the particular equipment, access, configuation, etc. which exist in an area and can be exploited by the adversary.

Two methods were used to generate sabotage possibilities. The first was to consult prior studies which had been done to analyze the consequences of sabotage or accidents at other fuel cycle facilities.

Relevant events from other studies are listed in Table 3-1. (Accident analyses are of interest because events which can occur accidently can usually be induced by the appropriate adversary actions.) The second method, sometimes termed the "Delphi Approach" was to gather together the study team to brainstorm about possible sabotage actions. Table 3-2 displays the matrix of target and waste form possibilities which exist from the HLW repository. Each applicable box was filled out by the two methods mentioned above. It was found that the repository, being an operationally simple facility, did not offer as many specific or intrinsic opportunities for sabotage as does, for example, a reprocessing plant.

The first step in screening analysis was to determine the criteria which reflect the analysis priority of the study participants. For this study, these criteria were determined to be the following:

1. Events of worst consequence should be considered so that the limiting public hazard may be evaluated.
2. Events for different locations but the same waste type should be analyzed to assess the intrinsic radioactivity retention properties of different locations in the waste repository.
3. All waste types should be examined so that relative consequences, and therefore relative safeguards requirements, may be inferred.
4. Ease in perpetrating the events should be factored into the screening analysis. This includes the availability of necessary materials, access, etc.

The next step was to estimate the relative consequences for the sabotage possibilities identified above. This was done by consulting prior studies (see Table 3-1) and by comparing inventories, release pathways, and radionuclide concentrations for the waste types. Finally, the screening was done for each waste type, and appears in Table 3-3. It can be observed that the consequences for waste forms other than spent fuel and HLW are expected to be smaller, but that events were selected for all waste forms to determine the relative consequences.

Table 3-1. Release Events from Other Studies

Target	Release Event	Safety or Sabotage Analysis Report	Material Released	Severity
Fuel Cleaning	Assembly drop or shear	G.E. Morris, Exxon	Noble gases, gaseous F.Ps	Slight
Fuel Storage Pool	Explosive rupture of assemblies in pool	SAI Sabotage Study	Noble gases, some particulates	Intermediate (mitigating effects of water as explosion damper and as decontaminator)
Fuel Storage Pool	Criticality	NFS	Noble gases, some iodine and volatile F.P s	Slight (decontaminating effect of pool water)
Fuel Handling Area	Explosive rupture of assemblies in air	SAI Sabotage Study	Noble gases, some semi-volatiles and particulates	Significant
LLW Storage	Fire in LLW Storage Vault	Exxon PSAR	Small amounts of Pu, other actinides	Slight (small amount of radioactive material released due to low concentration)
HLW Canister Pool	Breech HLW canister (vitrified waste intact)	Exxon PSAR	Small amount of F.P s leached out	Slight (not much waste released)
Fuel Cladding Storage	Fire in cladding storage container	Exxon PSAR	1% of material in hulls released	Slight (due to building filtration and limited amount of material in hulls)
Spent Fuel	Breach of Cask	Sandia (SAND77-1927)	100% noble gases 1.6% Cs 1% solids	Significant
Spent Fuel Cask	Breach of Cask	NUREG-0194	All noble gases, 1% volatiles, solids fraction parameterized-10^{-5}-10^{-2}	Significant
HLW in Cask	Breach of Cask	NUREG-0194	Solids fraction parametrized -10^{-5}-10^{-2}	Significant

Table 3-2. Sabotage Possibilities.

Waste Form	Receiving Yard	Unloading Area	Spent Fuel Storage Pool	Transfer and Drying Chamber	Receiving and Overpack Cells	Hoist Room	Subsurface Receiving Facility	Emplacement Hole
Spent Fuel	Attack on Cask: shaped charge projectile, thermal attack, mechanical opening, explosives	Explosives, assembly drop	Explosives, mechanical impact with crane, criticality	Explosives, assembly drop or shearing	Explosives, assembly drop or shearing	Hoist Drop, Explosives	Explosives, mechanical impact with transporter	Explosives, mechanical impact with transporter
High Level Waste	Attack on Cask: shaped charge projectile, thermal attack, mechanical opening, explosives	Explosives, canister drop	Not applicable	Not applicable	Explosives, canister drop or shearing	Hoist drop, explosives	Explosives, mechanical impact with transporter	Explosives, mechanical impact with transporter
Cladding Hulls	Attack on Cask: shaped charge projectile, thermal attack, mechanical opening, explosives	Explosion and/or fire	Not applicable	Not applicable	Explosion and/or fire	Hoist drop, explosion and/or fire	Explosion and/or fire	Explosion and/or fire, mechanical impact with transporter
TLW-TRU	Attack on Cask: shaped charge projectile, thermal attack, mechanical opening, explosives	Explosive dispersal	Not applicable	Not applicable	Explosive dispersal	Hoist drop, explosive dispersal	Explosive dispersal	Explosive dispersal, mechanical impact with transporter
LLW-TRU	Attack on "Super-Tiger" trailer transporter using explosives or incendiary device	Explosion or fire	Not applicable	Not applicable	Not applicable	Hoist drop, explosives	Fire, explosives	Fire, explosives

Table 3-3. Screening Analysis.

Waste Type	Considerations
Spent Fuel	Receiving Yard - Best possibility is large shaped charge or breaching charge/other studies (SAND77-1927, NUREG-0194) show significant consequences Surface Facility - Fuel assembly drop inconsequential (Exxon PSAR)/criticality in pool yields small consequences (NSF SAR)/explosive dispersal significant, but worse outside pool (SAI sabotage study)/best possibility for explosive dispersal in transfer and drying chamber (large inventory, high ventilation rate) Subsurface Area - Consequences reduced due to deposition in corridors/hoist drop is best possibility because of mechanism, inventory
High Level Waste	Receiving Yard - Best possibility is shaped charge or breaching charge/NUREG-0194 showed significant consequences Surface Facility - Hot Cell has largest inventory, is best possibility/explosive dispersal is mechanism Subsurface Facility - Consequences reduced due to deposition in corridors/however to investigate the difference in consequences between the mine and the surface facility, a release here should be investigated/hoist drop is best possibility because of mechanism, inventory
Cladding Hulls	Consequences much less than spent fuel or HLW because of smaller radionuclide inventory/should be examined to investigate relative consequences/best possibility is explosion and fire (since hulls can be burned) in receiving cell (surface facility)
Intermediate Level Waste	Consequences less than spent fuel or HLW because of smaller radionuclide inventory/solidified form of waste (probably in concrete) makes it difficult to disperse/to investigate relative consequences, best possibility is explosive dispersal in Hot Cell (surface facility)
Low Level Waste	Smallest consequences expected due to extremely small radionuclide content of waste/disposal much easier if LLW is combustible, so this was assumed/ best possibility (to investigate relative consequences) is fire in LLW handling building due to large inventory present there

Table 3-4, which depicts the selected reference events, lists separately the four forms of HLW considered herein. This distinction has not been necessary up to this point because the identification of possible sabotage events is not sensitive to these differences, but the following stages of the analysis (determination of release fractions, quantity released, calculation of consequences, etc.) require more complete specification of the waste type. Before proceeding to the discussion of release fractions and consequence analyses, the adversary actions to accomplish these reference events will be discussed. First, however, several significant points regarding the implied actions should be mentioned. No safeguards system or safeguards engineering was assumed to exist in the repository. Only those design features dictated by good engineering practice or necessary for safety considerations were assumed. Furthermore, the fact that no access control or security check was assumed made threat definition inapplicable. The adversary difficulty for all of the reference sabotage events was determined to be approximately equal, since these events were all chosen to represent the worst plausible sabotage actions that the adversary could perpetrate; in other words, this consideration tended to normalize the difficulty. Finally, the lack of detailed repository design information made it impossible to outline each of the adversary's steps. Therefore, only the major actions were listed and will be discussed.

The major adversary actions necessary to cause each of the references sabotage events are listed in Table 3-5. These are discussed below:

- Penetration of Cask - The greatest difficulty is in procuring a shaped charge and placing it accurately on the cask. Removal of some of the restraint and cooling structures on the cask may be necessary.

- Explosive Dispersal - For most of the explosive reference sabotage events, large amounts (several hundred pounds) of explosives are necessary to cause the event, and must be placed carefully in remote handling cells. This presents problems to the adversary in introducing these explosives to the plant and into the cells. If one of the alternate repository concepts (other than salt) is chosen, however, the explosives will be more readily available since some mining will be done by blasting.

Table 3-4. Reference Events

	LOCATION OF SABOTAGE EVENT		
	SURFACE LEVEL		MINE LEVEL
WASTE TYPE	YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
SPENT FUEL	PENETRATION OF CASK VIA SHAPED CHARGE OR BREACHING CHARGE	EXPLOSIVE DISPERSAL IN DRYING/TRANSFER CHAMBER	HOIST DROP
VITRIFIED HLW W/O PU	- SAME AS ABOVE -	EXPLOSIVE DISPERSAL IN HOT CELL	- SAME AS ABOVE -
VITRIFIED HLW W PU	- SAME AS ABOVE -	- SAME AS ABOVE -	- SAME AS ABOVE -
CALCINED HLW W/O PU	- SAME AS ABOVE -	- SAME AS ABOVE -	- SAME AS ABOVE -
CALCINED HLW W PU	- SAME AS ABOVE -	- SAME AS ABOVE -	- SAME AS ABOVE -
CLADDING HULLS		EXPLOSION AND FIRE IN RECEIVING CELL	
ILW		EXPLOSIVE DISPERSAL IN HOT CELL	
LLW-COMBUSTIBLE		FIRE IN LLW HANDLING BUILDING	
	GROUND LEVEL RELEASE	STACK RELEASE	

Table 3-5. Adversary Sabotage Actions.

		LOCATION OF SABOTAGE EVENT		
		SURFACE LEVEL		MINE LEVEL
		YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
WASTE TYPE	SPENT FUEL	ATTACH 42LB SHAPED CHARGE TO CASK	SET EXPLOSIVES UNDER ASSEMBLIES/SABOTAGE FILTERS/KEEP VENTILATION SYSTEM RUNNING	SABOTAGE HOIST/DEFEAT AIRLOCK AT BOTTOM/SABOTAGE FILTERS/KEEP VENTILATION SYSTEM RUNNING
	VITRIFIED HLW W/O PU	-SAME AS ABOVE-	-SAME AS ABOVE-	-SAME AS ABOVE-
	VITRIFIED HLW W PU	-SAME AS ABOVE-	-SAME AS ABOVE-	-SAME AS ABOVE-
	CALCINED HLW W/O PU	-SAME AS ABOVE-	-SAME AS ABOVE-	-SAME AS ABOVE-
	CALCINED HLW W PU	-SAME AS ABOVE-	-SAME AS ABOVE-	-SAME AS ABOVE-
	CLADDING HULLS		OPEN CANISTERS AND SPILL/IGNITE HULLS/SABOTAGE FILTERS/KEEP VENTILATION SYSTEM RUNNING	
	ILW		SET EXPLOSIVES UNDER CANISTER/SABOTAGE FILTERS/KEEP VENTILATION SYSTEM RUNNING	
	LLW-COMBUSTIBLE		OPEN SOME DRUMS/SET FIRE/SABOTAGE FILTERS/KEEP VENTILATION SYSTEM RUNNING	
		GROUND LEVEL RELEASE	STACK RELEASE	

- Sabotage HEPA Filters - There will be two sets of HEPA filters in each of the redundant filter legs. One set of filters may be changed out while ventilation flow is passing through the other, thus affording the adversary the opportunity to fail these filters and leave them off-line until the time of the sabotage event. At this time, the flow could be switched to the failed leg, allowing contamination to be vented to the atmosphere.

- Keep Ventilation System Running - Although detailed designs for the electrical and ventilation systems at the repository do not exist, it is expected that the adversary could gain easy access to the controls, switch boxes, and wiring. If he were knowledgeable about the system, he could rewire or "jumper" the controls at the proper time so that the system could not be shut off in the usual manner.

- Sabotage Hoist - Sabotage of the hoist would probably be one of the most difficult adversary actions due to the redundant safety mechanisms and interlocks which would exist, the substantial cable, and the difficulty in accessing the hoist (which will be in a remote access area). However, it is possible that the airlock could be opened while the hoist was at the bottom of the shaft and then canisters could be shoved down the shaft. (See next item for discussion of opening airlock.)

- Sabotage Hoist Airlock - This adversary action would be necessary to release the dispersed radioactivity after a hoist drop incident, and also if an attempt were made to drop canisters down the open shaft, as was outlined in the previous item. The airlock will probably be interlocked for safety, but these controls could be overridden by the appropriate adversary actions since access to the switches and wiring will not be controlled.

- Open Hull Canisters - The hulls are packed with sand in substantial canisters composed of 10" schedule 40 pipe with welded ends. To ignite the hulls, they must first be unpacked from the canister, separated from the sand, then ignited. Opening the canisters may be accomplished using either the welding equipment, which will probably be present in the hot cell, or by using explosives to shear open the container. In either case, the process will be time consuming and will be hampered by the fact that all operations must be conducted in a remote access cell.

- Ignite Hulls - The zirconium hulls, although combustible, do not readily burn unless fines are present. An ignition source is necessary; an incendiary device is preferable, since it produces a very high temperature, but solvents available at the repository may suffice.

- Ignite LLW - This is perhaps the easiest adversary action, provided that combustible waste is shipped to the repository. The most difficult part of the task may be locating the combustible waste among the many drums, although these will probably be marked. The waste drums are relatively easy to open, and the fire may be started with incendiary devices or with materials (e.g., solvents) available in the repository.

3.3 WASTE CONTAINER CONTENTS AND RELEASE FRACTIONS

This section describes the radionuclide contents of the various waste containers and the estimated fractional release for the reference sabotage events. The estimation of fractional release was performed in two parts, release from the waste container to the immediate surroundings and, for those cases in which the container was inside the facility, release from the facility.

The waste container release fractions were estimated based on data, estimates or methods used in previous studies. Unfortunately, these data and estimates are subject to large uncertainties, but better data and methods probably do not exist at this time. Also, there are not good estimates of the magnitudes of uncertainties and these release fractions, although in some cases different values were given with the labels "upper estimate", "best estimate" and "lower estimate". The fact remains that there are no good experimental data on release fractions for most of the reference sabotage events and therefore no solid basis for the release estimates used.

Release fractions from the facility were calculated using standard computer programs and methods such as DUCT and HAARM, which are discussed later. Two different cases were considered: dispersal inside the surface facility, and dispersal inside the mine. In both cases, the transport pathway out of the facility was assumed to be via the ventilation system. This pathway was chosen for two reasons: first, it did not require the creation of an aperature through the heavy shielding wall, with its concommitant necessity for more explosives and adversary timing, and second, it provided a motive force for the dispersed material via the ventilation flowrate. The assumptions made concerning the ventilation system were that the HEPA filters were rendered ineffective, and that the system was kept running for 30 minutes following the dispersal event. The implications of these assumptions on adversary actions were addressed in Section 3.2.

3.3.1 Radionuclide Contents of Waste Containers

Table 3-6 shows the radionuclide contents assumed for containers of the various waste forms. The waste will, of course, contain radionuclides other than the 25 listed in Table 3-6, but it is expected that all the major contributors to human exposure are included. The data for the PWR spent fuel assembly were derived by extrapolating data from Reference 4 for 10-year cooled spent fuel to 6.5 years cooling. The data for HLW apply to both vitrified or calcined HLW without Pu. Actually, there is some Pu in HLW "without Pu", because chemical processing typically removes only about 99.5% of the Pu. To obtain data for HLW "with Pu", the Pu contents shown for HLW in Table 3-6 may be multiplied by a factor of 200.

The contents of a canister of cladding hulls were derived from data in Reference 6, which gave PWR cladding waste activites for 5 years cooling in curies per metric ton of heavy metal (MTHM). Each cladding waste canister was assumed to hold cladding wastes from 4 MTHM, based on data from Reference 5.

The contents of ILW and LLW drums were obtained from Appendix E of Reference 4 (WIPP DEIS). The WIPP ILW and LLW data are for defense TRU wastes, but are assumed to apply to commercial TRU wastes as well. The WIPP LLW data were used without modification, but the WIPP ILW data, which was for a 4500 kg, 1200 liter internal volume container, was reduced by a factor of 5 for the smaller, 55-gallon commercial ILW drum considered here.

3.3.2 Release Fractions from Waste Container

This subsection describes the estimates of fractional release from the waste container which were obtained for the reference sabotage events. Limited existing data and estimates from previous studies were used to obtain the release fractions. The estimates so obtained reflect the lack of good data for these kinds of releases.

Table 3-6. Radionuclide contents of single fuel assembly, canister or drum (contents in curies)

NUCLIDE	HALF LIFE	PWR FUEL ASSEMBLY*	HLW CANISTER**	HULLS CANISTER	ILW DRUM	LLW DRUM
H-3	12.33 YR	183	-	-	-	-
C-14	5730 YR	0.051	-	-	-	-
FE-55	2.7 YR	712	-	-	-	-
CO-60	5.27 YR	1000	-	-	.52	-
NI-63	100 YR	225	-	-	-	-
KR-85	10.72 YR	3250				-
SR-90/Y-90	29 YR	32500	1.6X10^{5}	136	84	-
RU-106/RH-106	368 D	2572	1100	390	.74	-
SB-125	2.73 YR	852	9800	60.4	-	-
I-129	1.59X10^{7} YR	0.016	-	6.8X10^{-5}	-	-
CS-134	2.062 YR	14000	19000	98.4	-	-
CS-137/BA-137M	30.17 YR	43400	2.3X10^{5}	194	.42	-
CE-144/PR-144	284.4 D	1694	270	25	-	-
PM-147	2.6234 YR	9078	1.9X10^{4}	55	-	-
EU-154	8.2 YR	3228	1.2X10^{4}	17	.42	-
EU-155	4.76 YR	450	370	2.6	-	-
NP-237	2.14X10^{6} YR	0.16	-	-	-	-
PU-238	87.74 YR	1336	250	4.6	.02	.041
PU-239	2.411X10^{4} YR	150	4.4	.66	.26	.48
PU-240	6537 YR	220	12	.98	.06	.12
PU-241	14.7 YR	36600	860	200	1.6	2.9
PU-242	3.75X10^{5} YR	1.14	-	-	-	-
AM-241	432 YR	674	440	2.1	.04	.008
CM-242	162.8 D	752	6	.03	-	-
CM-244	18.114 YR	1006	4400	3.26	1.1	-

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* 6.5 YEARS COOLING

** W/O PU. FOR CANISTERS WITH PU, MULTIPLY PU QUANTITIES BY 200.

In many cases, non-mechanistic release estimates were used since the actual release phenomena could not be modelled; wherever possible, however, these estimates were checked using scoping or bounding calculations. Another important consideration is that the wide range of plausible initiating conditions makes extensive analysis of the intiating events inappropriate.

Spent Fuel in Shipping Cask

Shipping casks used to transport spent fuel assemblies to the Waste Repository by truck or by rail are massive objects. They usually consist of many inches of steel and lead (or depleted uranium) as gamma shielding and structural material, as well as water or organic material for neutron shielding. Their resistance to damage due to impact or fire is well documented (reference 9). The cask considered for on-site sabotage releases was a rail cask containing 10 PWR assemblies. For the theft/sabotage event, a truck cask with one-third the capacity of the rail cask, and also one-third of the rail cask release, was assumed because theft of a rail cask with subsequent transport to a large urban area was believed to be incredible.

NUREG-0194[10] has stated that massive rupture of a cask is considered incredible, and has therefore assessed the best possibility for release as being small bore penetration. Based on this mechanism, that study parameterized solids release fractions from 10^{-5} to 10^{-2}. Sandia Laboratories' study of the consequence of spent fuel sabotage, NUREG/CR-0996[7] assessed several possibilities for achieving release from a cask, and estimated three combinations of release fractions which parameterized the solids release fractions from 7×10^{-4} to 2×10^{-3}.

Based on these studies, and taking into consideration the difficulty in causing release from a spent fuel cask, it was determined that the reference release mechanism is penetration with a large breaching charge or shaped charge. Shoulder-fired or small anti-tank weapons are probably capable of penetrating the cask, but the hole would be small, the damage to the contents would be minimal, and the resulting release would be small.

The placement of a large shaped charge (15-40 lbs) or breaching charge (several hundred pounds) could also present difficulties, but was determined to be feasible for a sophisticated adversary.

The amount of material released in such a manner could not be determined by detailed modeling, so values were chosen consistent with previous studies. These are release of 10% noble gases, 7 x 10^{-2}% semi-volatiles and 7 x 10^{-2}% particulates, all applying to the entire 10 assembly inventory. These estimates include allowance for cask retention and are assumed to represent air transportable and respirable particle sizes (less than ten microns aerodynamic diameter), so that no further correction factor need be applied.

It is appropriate to point out here that the Sandia release fraction estimates used here are just that, i.e., estimates. Although Sandia has performed some explosive experiments (1975-1976) on spent fuel shipping cask surrogates, those results have not been accepted as definitive by the nuclear community.

Spent Fuel in Drying and Transfer Cell

This area potentially contains a large inventory of spent fuel (100 assemblies) stored in racks on the walls and in dryers. To determine how much activity would be released using a large but reasonable amount of explosives (several hundred pounds), information was used from a study on the effects of sabotage at a spent fuel receiving and storage facility.[11] An estimate was made on the amount of explosives required to rupture the cladding of two adjacent fuel assemblies if the charge were placed in between. It was determined that about 2 pounds of explosives would be necessary. However, this charge was assessed to only result in particulate releases of 10^{-5} since the explosion would not be violent enough to pulverize a large quantity of material. Using these values it would require 100 pounds of explosives to disperse material from the 100 assemblies and the total release would thus be 10^{-3} of one assembly. It was postulated that, alternatively, it may be possible to set several hundred pounds of explosives under two assemblies to result in the same aggregate release of

0.1% particulates in the respirable range. It was also assumed that the shock of the explosion would rupture the cladding of 20 assemblies resulting in the release of 10% of the noble gases from those assemblies.

Spent Fuel Release Due to Hoist Drop

It was calculated that the energy of an assembly dropping 2000 feet is about the same as contained in a pound of explosives; however, the coupling factor would be much greater than if that charge were set off near the assembly since the energy of motion is uniformly distributed throughout the assembly and will be efficiently converted when the assembly strikes the ground (assumed to be an essentially unyielding surface). When this factor is accounted for, the effective energy delivered to the assembly is probably near that of a hundred pounds of explosives. Therefore, the assumption was made that the four assemblies dropped down the shaft release 0.1% of the solids as respirable aerosol and 10% of the noble gases, consistent with the previous case.

Vitrified HLW from Cask

By reasoning similar to that for spent fuel in a cask, a shaped charge attack was assumed in which the entire inventory of a cask (9 canisters) is affected, and the release fraction for particles in the respirable range is 0.1% of the inventory. This falls in the range of estimates in Reference 8.

Vitrified HLW in Hot Cell

It is assumed that the adversary could place several hundred pounds of explosives under one HLW canister weighing approximately 1700 pounds and cause a release of 1% of the contents as a respirable aerosol. This release fraction is in line with the estimates from Reference 8.

Vitrified Waste Dropped Down Hoist Shaft

Tests performed at PNL[12] have shown minimal fines (<10) generation fractions (<.1%) for vitrified HLW impacted on unyielding surfaces up to 35 m/second. Terminal velocities in this event may exceed this value, although the assumption of an unyielding surface may not apply due to compression of the hoist structure on impact, making the effective impact velocity less. In the absence of better data, however, it is assumed that 1% of the four assemblies which are postulated to be dropped down the hoist shaft is released as an aerosol of respirable size.

Calcined Waste from Cask

It was assumed that, in an attack on a cask with 20 calcined waste canisters, 4% of the cask inventory is released. This value was estimated by considering the volume of HLW which would be affected by a large shaped charge, then assuming that that amount of material would be expelled from the cask. No credit was taken for cask retention, since this effect was not possible to model during the cask blowdown. (The cask cavity is normally pressurized with helium to 24 psig.) Also, no credit was given to possible particle agglomeration and subsequent settling to the ground. The authors believe, based on intuition, that a significant portion of the calcined powder expelled from the cask would compact together and fall to the ground. Unfortunately, this effect could not be quantified because of a lack of data or method of calculation, and the effect was therefore neglected.

Based on size distribution data from PNL (see Appendix B), which indicated that about 1% (by mass) of spray calcined material would be in the respirable range, a respirable release fraction of 0.006 was derived.

Calcined Waste in Receiving Cell

The amount of powder in a calcined HLW canister is approximately 500 pounds.[13] It is postulated that an adversary is successful in placing several hundred pounds of explosives under one canister, and that the resulting explosion lofts 100% of this material. This would be a substantial amount of powder for this much explosive to effectively disperse, and makes the single canister assumption plausible. A parametric analysis, discussed in Section 3.3.3, showed that the amount of powder released from the facility is not very sensitive to the amount of powder lofted, since for large amounts lofted, the processes of agglomeration and settling rapidly clear the air and reduce releases from the cell. One hundred percent of the contents of one calcined waste canister, of which 15% is of respirable size, was therefore assumed to be released to the receiving cell.

Calcined HLW Dropped Down Shaft

It was assumed that 100% of contents of the four Calcined HLW canisters postulated to be dropped down the hoist shaft is dispersed, in accordance with previous assumptions concerning the amount of energy delivered to the canisters in the fall and the dispersability of the calcined material. Of this material, 15% was assumed to be of respirable size.

Cladding Wastes in Hot Cell

It was postulated that the adversary arranges a fire to burn cladding hulls in the hot cell by opening 10% of the canisters (6 canisters) and then igniting them with an incendiary device. The opening can be accomplished using welding equipment in the cell or by using explosive charges to shear the canisters. (The 10% value corresponds to an estimate of the number which can be opened in a single shift).

The EXXON PSAR for the Nuclear Fuel Recovery and Recycling Center[14] has analyzed a zirconium cladding fire, and has estimated a release fraction of 1% of the material as a transportable aerosol based on experiments with plutonium fires. That 1% value was used here.

ILW in Cell

The ILW, which is shipped in a fixed form (assumed to be concrete or something similar) in drums, was assumed to be dispersed with several hundred pounds of explosives. The contents of a single barrel, weighing over a thousand pounds, was assumed to be dispersed, resulting in appoximately 1% release of particulates in the respirable range. This is an engineering estimate, and is consistent with those made for releases of vitrified wastes earlier in this section.

LLW in LLW Handling Building

Unless specifically precluded, the LLW received at the repository will consist of both flammable and non-flammable items. It was postulated that 10% of the estimated 1000-drum inventory in the LLW handling building is burned by the adversary. This accounts for the fact that some of the drums will be non-flammable, firewalls will probably be erected to divide the storage into compartments, and the adversary will have difficulty opening, igniting, and burning all the flammable drums. The estimate of the fraction of respirable aerosol released (0.3%) was taken from Reference 15, which describes experiments to develop release fractions from the burning of contaminated wastes.

Table 3-7 contains the release fractions from containers as described in the preceding paragraphs. It also contains release fractions from the facility, which are discussed in the next section.

3.3.3 Release Fraction From Facility

Once the release fractions of the radioactivity from the container were determined, it was necessary to examine the mechanisms of inter-facility transport (for events other than those which occur in the railyard) to see whether a reduction in the final source term was appropriate.

Table 3-7. Reference Sabotage Events Release Fractions.

Quantity of material affected
Release fraction from container/release fraction from facility

		LOCATION OF SABOTAGE EVENT		
		SURFACE LEVEL		MINE LEVEL
		YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
WASTE TYPE	SPENT FUEL	10 PWR Assemblies 0.0007 (0.1 NG)/1.	2/20 PWR Assemblies* 0.001 (0.1 NG)/.9	4 PWR Assemblies 0.001 (0.1 NG)/0.67
	VITRIFIED HLW W/O PU	9 Canisters 0.001/1.0	2 Canisters 0.01/0.8	4 Canisters 0.01/0.78
	VITRIFIED HLW W PU	9 Canisters 0.001/1.0	2 Canisters 0.01/0.8	4 Canisters 0.01/0.78
	CALCINED HLW W/O PU	20 Canisters 0.006/1.0	2 Canisters 0.15/1.0	4 Canisters 0.15/0.44
	CALCINED HLW W PU	20 Canisters 0.006/1.0	2 Canisters 0.15/1.0	4 Canisters 0.15/0.44
	CLADDING HULLS		6 Canisters 0.01/1.0	
	ILW		1 Drum 0.01/1.0	
	LLW COMBUSTIBLE		100 Drums 0.003/1.0	
		GROUND LEVEL RELEASE	STACK RELEASE	

*Particulates released from 2 assemblies, noble gases from 20 assemblies.

Release From the Surface Facility

All releases in the surface facility were assumed to occur in a cell 30' x 50' x 20' and ventilated at six air exchanges per hour, both assumptions being consistent with the expected design of the generic repository. The models used to estimate the cell leakage via the ventilation system were the HAARM aerosol agglomeration code and the DUCT ventilation system modeling code. These codes are discussed in Appendix A.

The first case which was examined was the dispersal of spent fuel in a cell. It was assumed that some adversary action damages 2 PWR spent fuel assemblies such that 0.1 percent by weight of the UO_2 (with associated fission products and transuranic nuclides) is reduced to dispersable aerosol. The initial result is the uniform dispersal of 1×10^3g of irradiated fuel into a cell 850 m^3 ventilated at 6 air changes per hour. A particle size distribution was required so that the models could be used to predict settling and deposition, even though no size data exists. Therefore, a particle size distribution was assumed with a Mass Median Diameter (MMD) of 1.25μ and a geometric standard deviation (σ_g) of 1.68. This distribution reflects the complete lack of knowledge on the particle size, and thus is extreme in that it yields a fully respirable dispersion, i.e., nearly all of the dispersed mass occurs in particles smaller than 10 m aerodynamic diameter. The resulting leakage from the cell was approximately 90% of the material released.

The second case examined was the release of vitrified HLW aerosol from a cell. In this case, it was assumed that explosive damage was done to one HLW canister such that 1 weight percent of the contents was released as a fully released respirable aerosol. The HLW particle mass density is taken as 2.8 g/cm^3, and the aerosol is described as having a log-normal particle size distribution with an MMD of 1.5 μm and a σ_g of 2. This, again, reflects a lack of data and therefore assumes that almost all particles are less than 10μ. Approximately 7×10^3 g of vitrified HLW would be dispersed into a cell of 850 m^3 ventilated at 6 air changes per hour. Similar to the above event, about 80% of the dispersal material would be released from the cell.

The final case which was examined for release in the surface facility corresponded to explosive dispersal of calcined powder in a cell. Although it was assumed that the contents of one HLW canister was completely dispersed in the cell, a parametric study was done to investigate the effects of dispersal of larger amounts of powder in the cell, since there was some concern about the ready dispersability of calcined powder.

The amount of calcined powder lofted in the cell was parameterized at 100%, 10% and 1% of the total inventory. A log normal distribution with a mass median diameter (MMD) of 10μ and a geometric standard deviation of 3 was chosen, consistent with information obtained earlier in the study.

Results of the HAARM code calculations are given in Table 3-8. The fraction of the dispersed calcine which was released from the cell into the ventilation system is seen to range from 0.03 for the case of complete dispersal, to 0.58 for the case of 0.01 dispersal. The small release fraction for the first case is due to the extremely high particle concentration when the full 1.15 x 10^7 g is dispersed into the cell (1.5 x 10^9 particles/cm^3). Particle agglomeration proceeds very rapidly, producing a new MMD of 50 μm within a few seconds. These particles fall out quickly, significantly inhibiting transport of the aerosol. Particle agglomeration is progressively less important for the second and third cases of fractional dispersal.

Additional deposition of the calcine should occur in the ventilation system. This was calculated assuming a 1.5 foot ventilation duct 75 feet long with an air speed of 30 feet/second. Fractional releases through this duct are also given in Table 3-3. As was the case with release from the cell, the fraction released through the duct increases, from 0.35 to 0.8, as the fraction dispersed into the cell decreases from 1.0 to 0.01. This is due to the heavier particle size distribution of the aerosol entering the duct for the cases of highest initial particle concentrations, and therfore the greatest consequence agglomeration.

Table 3-8. Calculated Airborne Releases of Spray Calcine HLW From Dry HLW Storage Cell to Outside Environment

	Fraction of Total Storage Cell Contents Dispersed into Cell Atmosphere		
	1.00	0.10	0.01
Calcine Stored in Cell, g	1.2×10^7	1.2×10^7	1.2×10^7
Calcine Dispersed into Cell Atmosphere:			
Mass, g	1.2×10^7	1.2×10^6	1.2×10^5
MMD, µm	10	10	10
AMD, µm	20	20	20
σ_g	3	3	3
Fraction Respirable	0.26	0.26	0.26
Mass Respirable, g	3.0×10^6	3.0×10^5	3.0×10^4
Calcine Fraction Released:			
From Cell	0.03	0.19	0.58
Through Duct	0.35	0.66	0.82
Net	0.01	0.13	0.48
Calcine Released to Outside Environment:			
Mass, g	1.2×10^5	1.5×10^5	5.5×10^4
~ MMD, µm	13	7	5
Fraction Respirable	0.15	0.35	0.54
Mass Respirable, g	1.7×10^4	5.2×10^4	3.0×10^4

Note: Particle size distributions are assumed to be log-normal, for which:

MMD is mass median diameter
AMD is aerodynamic median diameter
σ_g is geometric standard deviation
Respirable means ≤ 10 µm (aerodynamic) diameter

The combined result of releases from the cell and duct was a calculated release fraction ranging from 0.01 for total initial dispersal of the calcine into the cell, to about 0.05 for 1% dispersal. While the mass of HLW dispersed varied by a factor of 100, the total mass of calcine released to the outside environment varied by a factor of only 3: from 5.5×10^4 g to 1.5×10^5 g. The different particle size distributions of the effluents led to a range of respirable fractions so that the respirable mass in the released aerosol also varied over a factor of 3: from 1.7×10^4 g to 5.2×10^4 g. In the case where 1% of the inventory was released, there is no reduction in the respirable mass since only the larger particles deposit out. The important observation is that the amount of calcined HLW which is released to the outside environment may be fairly insensitive to the inventory stored in the cell, or to the adversary's degree of success in damaging the canisters.

For this reference event, the dispersal of one canister of HLW in the cell was postulated. Since this is near to the case where 1% of the inventory is lofted, it is expected that there will be no reduction in the mass of respirable particles released.

Release from the surface facility was not evaluated for those events expected to be of much less serious consequence (such as dispersal of cladding hulls, ILW and LLW). It was assumed for these cases that 100% of the material released in the cell was released to the outside.

Releases From the Mine

Several sabotage events were assumed to occur via hoist drop, so that the transport path for radioactivity release from the facility was via the mine ventilation system. To evaluate the effects of deposition in the mine, a model of the ventilation system was constructed using some drawings and general design criteria from the Parsons, Brinkerhoff, Quade, and Douglas[1] conceptual design. Figure 3-1 presents the corridor runs which were developed for the model.

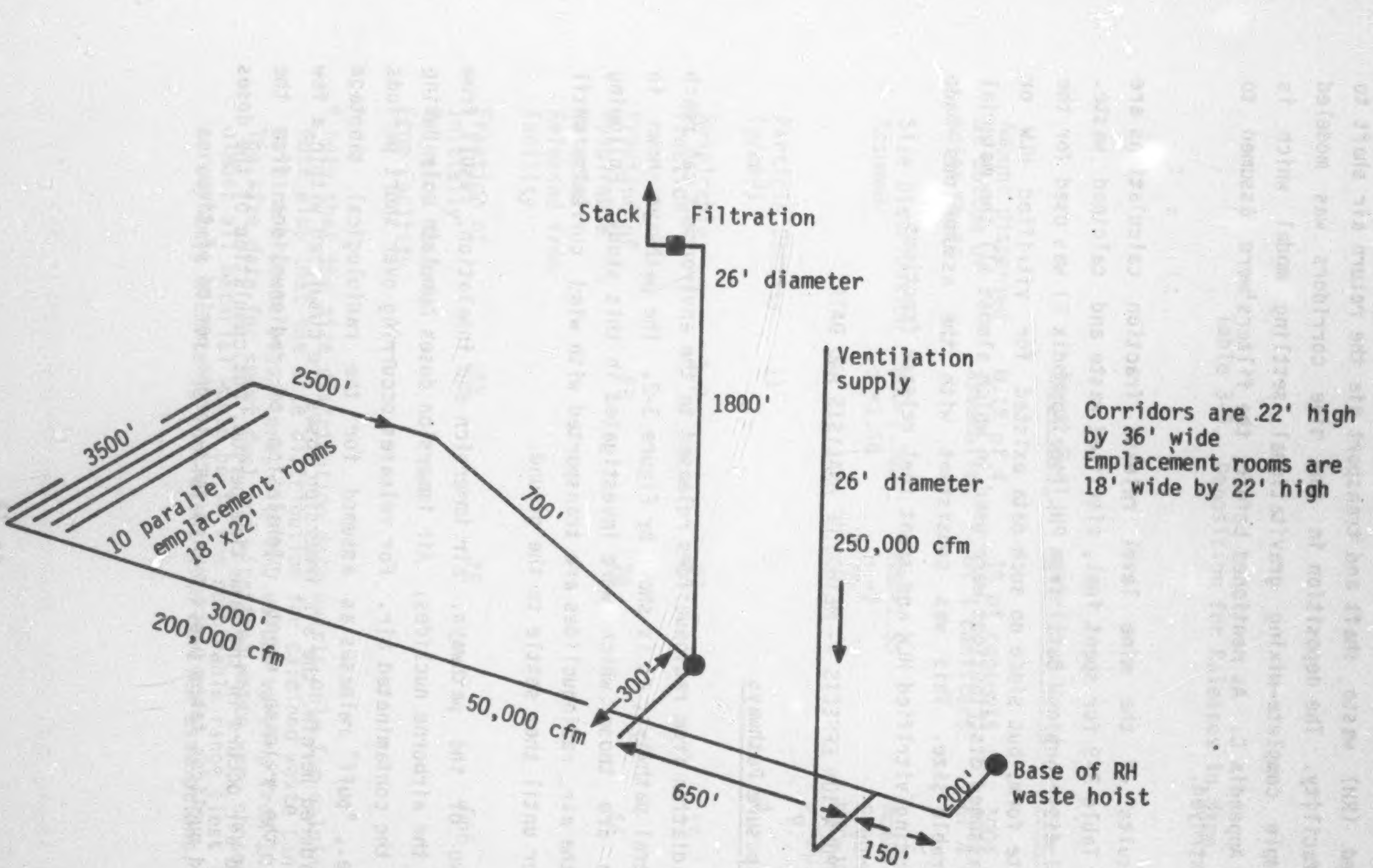

Figure 3-1. Assumed mine level ventilation schematic

Calculations were performed for release from the base of the remote-handled (RH) waste shaft and transport via the return air shaft to outside the facility. The deposition in the mine corridors was modeled using a simple complete-mixing gravitational settling model which is discussed in Appendix C. As mentioned before, the filters were assumed to have been destroyed.

Results of the mine level release fraction calculations are presented in Table 3-9 for spent fuel, vitrified waste and calcined waste. Actual size distribution data from PNL (see Appendix B) was used for the calcined waste form, but since no such data existed for vitrified HLW or spent fuel, assumed distributions were used in which almost all the material was of respirable size. This was consistent with the assumptions made earlier regarding vitrified HLW and spent fuel release fractions.

3.4 POPULATION EFFECTS -- METHOD OF ANALYSIS AND DATA

3.4.1 Exposure Pathways

Radiation from radionuclides released to the environment can reach man via several pathways, as is shown by Figure 3-2. The pathways shown in this figure are those which were investigated in this study. Following release to the air, radionuclides are transported with wind currents until they decay or until they settle to the ground.

Two of the pathways, air immersion and inhalation, result from exposure to the airborne nuclides. Air immersion doses cumulate only during passage of the contaminated air. For releases occurring over short periods of time, i.e., "puff" releases as assumed for the radiological sabotage events considered herein, the air immersion doses are cumulated within a few hours after the release event. Inhalation of radionuclides from the contaminated air occurs in the same time period, but cumulation of the doses from inhaled nuclides takes place over a much longer period of time.

Table 3-9. Deposition for Releases in Mine

	Spent Fuel	Vitrified Waste	Calcined Waste
Amount Dispersed at Bottom of Hoist Shaft	0.1% of 4 assemblies	1% of contents of 4 canisters	100% of contents of 4 canisters
Size Distribution Assumed*	MMD=1.25μ σ_g=1.68	MMD=1.5μ σ_g=2	Actual data per Figure B-1, MMD≈10μ σ_g=2μ
Particle Density (g/cm^3)	11	3	4
Respirable Fraction	1.0	.97	.15
Fraction of Respirable Material Released from Facility	.68	.78	.44
Fraction of Initially Released Material From Facility	.68	.76	.066

* Note that the size distribution data exists only for calcined waste. Note also that the size distribution for calcined waste can vary with calcine process parameters, with MMD values varying from 10 to 120μ. The size data for spent fuel and vitrified waste were chosen so that almost all material would be in the respirable range (less than 10μ aerodynamic diameter), consistent with earlier assumptions.

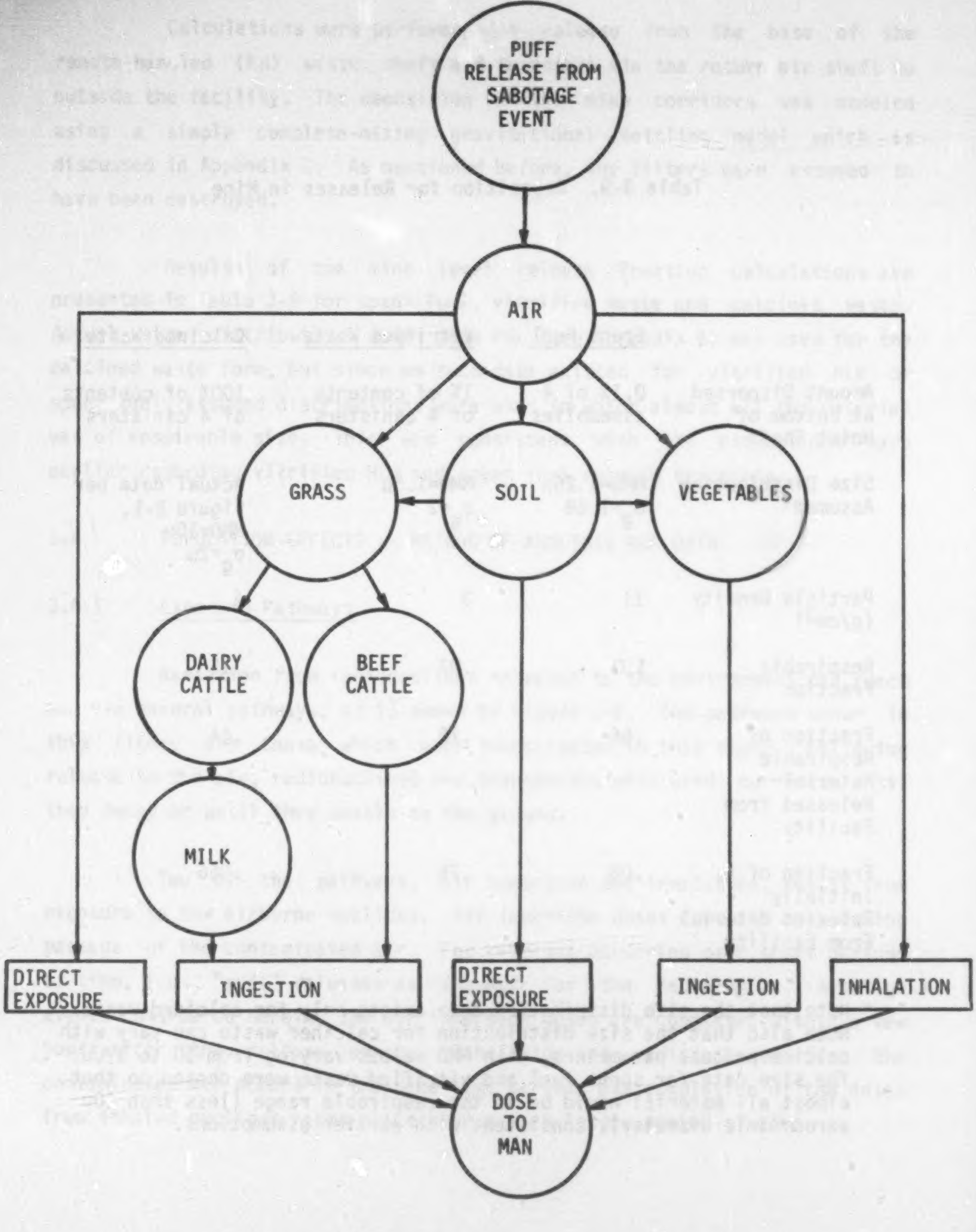

Figure 3-2. Major pathways for radionuclides released by a sabotage event

Surface exposure and ingestion doses result from exposure to nuclides which have settled to the ground or vegetation. Like air immersion doses, surface doses are external, but surface doses continue to cumulate as long as man remains in the contaminated area. Ingestion doses result from the eating or drinking of contaminated foods and liquids. Like inhalation doses, ingestion doses are internal, and once the nuclides are ingested, exposure cumulates for extended periods of time. For radionuclides with long biological half-lives, this "extended period of time" can be the lifetime of the affected individual. In this study, dose commitment times of 50 years were assumed for the ingestion and inhalation pathways.

After a severe radiological release event, radiation exposures from the ingestion and surface exposure pathways can be reduced by food interdiction, evacuation and decontamination. Food interdiction, which would most likely involve destruction of significantly contaminated foods, could reduce ingestion exposures to a small fraction of that acquired without interdiction. In this study, the two limiting food ingestion conditions were analyzed: complete food interdiction, and no food interdiction. Evacuation, if accomplished early enough, would reduce exposure to the air immersion, inhalation and surface exposure pathways. Evacuation would have to be accomplished very quickly after the release event, however, to be effective for the air immersion and inhalation pathways. Depending on wind speed and distance from the release location, evacuation would have to be accomplished within minutes or hours of the event. It is doubtful that the release event could be detected and described, the population informed and the evacuation completed in time to protect against the air immersion and inhalation exposure pathways. A mean evacuation time of 24 hours has been assumed for those release events severe enough to justify evacuation. An evacuation time of 24 hours would not be short enough to protect against the air immersion or inhalation exposure pathways, but would reduce the cumulated dose from ground exposure.

3.4.2 Population Dose

Population exposure for the sabotage release events was calculated with the ORNL AIRDOS-II computer program.[16] AIRDOS-II calculates the atmospheric transport of radionuclides by use of a Gaussian plume model, and calculates contaminated food ingestion with the food pathway model shown in Figure 3-3. Once the radionuclide concentrations in air, on the ground and in food are calculated, population or maximum individual doses are calculated by organ for the several exposure pathways described earlier. Calculation of these organ doses is facilitated by use of dose factor data, which (except for the radionuclide transport and food balance calculations) simplify the calculations to bookkeeping operations.

Input data to AIRDOS-II include the radionuclide release (by nuclide), wind data frequency distribution (by direction, velocity and Pasquill stability), population data (array for 16 directions and up to 20 radial distances), agriculture data (milk cows, beef cattle, vegetable food crop areas, same size arrays as for population), food balance and consumption data, and dose factor data (see Figure 3-4). As mentioned above, use of the dose factor data is key to the operation of the AIRDOS-II code. These dose factors are pre-calculated doses which a specific organ will receive as a result of exposure to a specified quantity of a certain radionuclide. For example, the inhalation dose factor used for bone dose from Sr-90 was 0.0124 mrem per microcurie inhaled. A large array of dose factors was required to describe doses for the matrix of organs, radionuclides and exposure pathways considered.

AIRDOS-II was written primarily to calculate annual population doses or maximum individual doses for small continuous radionuclide releases which might occur from nuclear facilities, but AIRDOS-II is also applicable for calculating doses for puff radionuclide releases provided that specified input measures are taken. The specified input measures are as follows: (1) input the radionuclide release as a continuous release over a time of one year. Thus, a puff release of 1 curie (10^{12} picocuries) would be input as a release of 10^{12} divided by (365 x 24 x 3600) or 31710 picocuries per second, (2) input the surface dose cumulation time as the radionuclide buildup time

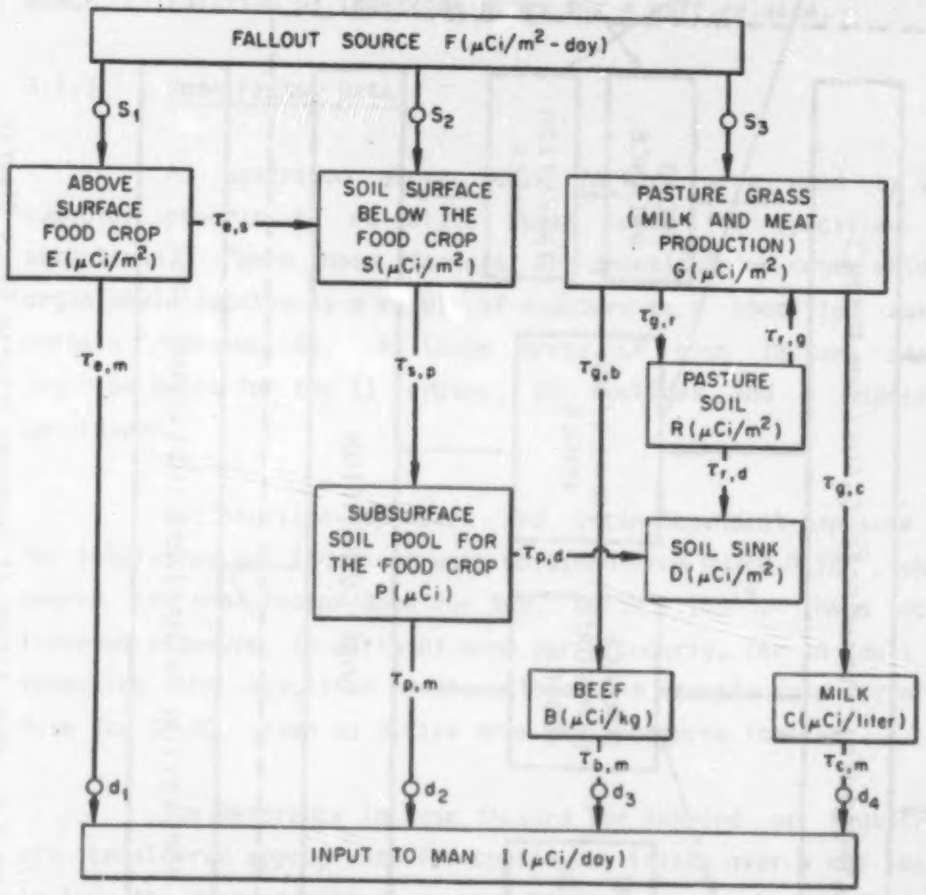
FALLOUT SOURCE F(μCi/m² - day)
S1
S2
S3
ABOVE SURFACE FOOD CROP E(μCi/m²)
τe,s
SOIL SURFACE BELOW THE FOOD CROP S(μCi/m²)
PASTURE GRASS (MILK AND MEAT PRODUCTION) G(μCi/m²)
τg,r
τr,g
τe,m
τs,p
τg,b
PASTURE SOIL R(μCi/m²)
τr,d
τg,c
SUBSURFACE SOIL POOL FOR THE FOOD CROP P(μCi)
τp,d
SOIL SINK D(μCi/m²)
τp,m
BEEF B(μCi/kg)
MILK C(μCi/liter)
τb,m
τc,m
d1
d2
d3
d4
INPUT TO MAN I(μCi/day)

Figure 3-3. AIRDOS-II food pathways model (figure from Reference 17)

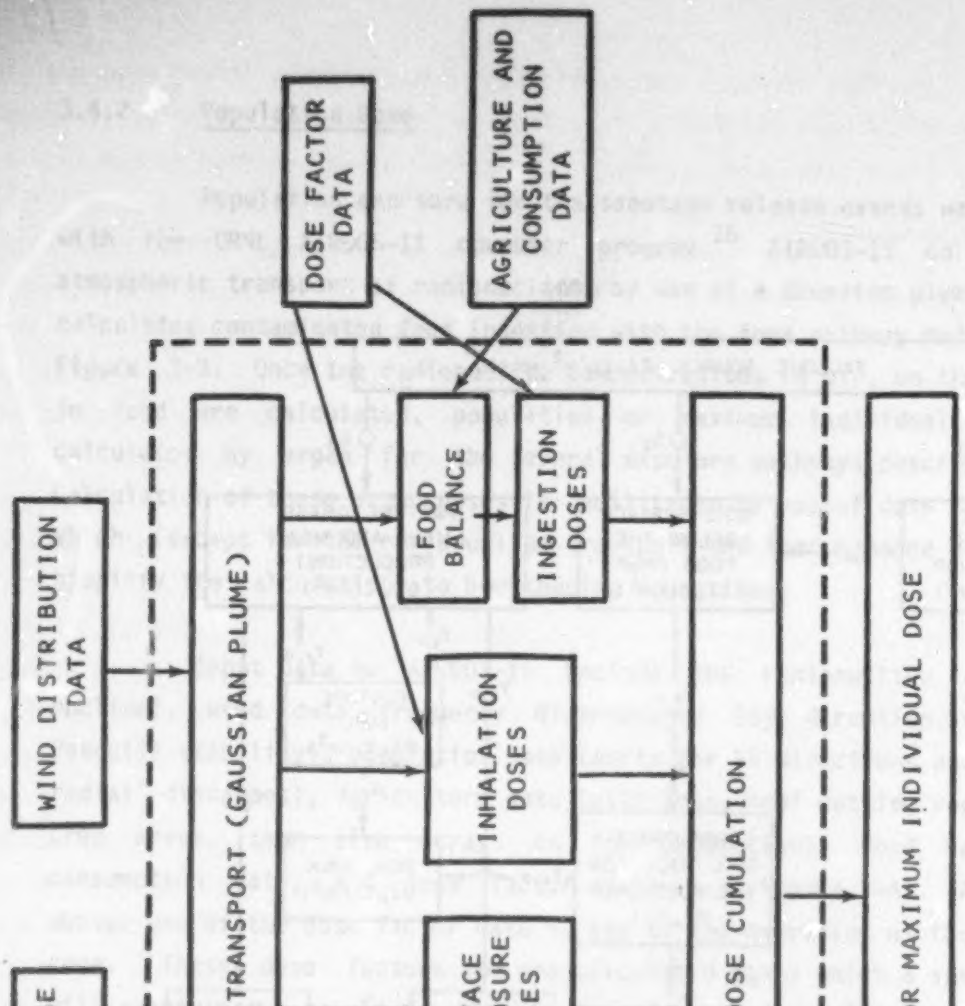

Figure 3-4. ORNL AIRDOS-II Computer Program Block Diagram.

(AIRDOS variable T) and (3) input wind conditions representative of conditions at the time of a pulse release rather than annual average wind conditions.

The result is a mathematically correct calculation of air immersion, inhalation and surface doses and a reasonable, although not exact, calculation of ingestion doses for a puff release.

3.4.3 Dose Factor Data

As described above, dose factors were used by the AIRDOS-II computer program to calculate human doses for specified radiological situations. These dose factors are precalculated doses which a specific organ would receive as a result of exposure to a specified quantity of a certain radionuclide. A large array of dose factors was required to describe doses for the 11 organs, 25 nuclides and 4 exposure pathways considered.

Radionuclide-dependent and organ-dependent exposure dose factors for inhalation and ingestion were obtained from NUREG-0172[18], which is the source of dose factor data for Reg. Guide 1.109[19]. These tables give the internal exposure, in units of mrem per picocurie, for an adult inhaling or ingesting the specified radionuclide. An example dose factor is the bone dose for Sr-90, given as 0.0124 mrem per picocurie inhaled.

The Reference 18 dose factors for inhaled or ingested particles are considered appropriate for continuous intake over a one year period and include the dose commitment over a fifty-year period. These data were assumed to also apply for short-term intake. The dose models employed in the derivation of these factors were based primarily on a 1959 report of Committee 2 of the International Commission on Radiological Protection (ICRP) as updated by ICRP reports 6 and 10. While the solubility and biological characteristics of the various radionuclides in their anticipated chemical form were taken into account, no consideration was apparently given to the effects of different particle sizes. Clearly, for low solubility materials, the dose from small (<1 micron diameter) particles is larger than the dose from an equal quantity (in curies) of larger particles because of the capability of these smaller particles to pass through and be absorbed in body tissue. Larger ingested paticles will tend to pass through the intestine without being absorbed, and the larger inhaled particles will tend to be eliminated by cillary-mucous transport after deposition higher in the nasopharyngeal tract.

External dose factors for air immersion and surface contamination exposure were obtained from Reference 19 (ORNL 4992), Tables 3-8 and Tables 3-9, respectively. These tables give external dose rates in mrem per year per microcurie per cubic centimeter (air immersion) and in mrem per year per microcurie per square centimeter (surface exposure).

3.4.4 Health Risk Estimates

The estimation of health risk effects from individual and population doses is complicated by the lack of good human data relating radiation exposure to health effects. Health risk estimates do, however, exist. The estimate of 450 rem LD50 for acute radiation dose has been in general use for many years and was used in this study. More important to this study, however, are the effects of low-level radiation on the population.

Much literature in recent years has concerned itself with estimating the extent of cancer incidence and mortality resulting from low levels of ionizing radiation. While there is some theoretical basis for the belief that very low levels of radiation can cause cancer, measurements of the cancer incidence and mortality have come largely from exposures to comparatively high levels of radiation which were delivered at high dose rates. The externally exposed population groups which have been the most widely studied are the atomic bomb survivors of Hiroshima and Nagasaki, a group of British patients who were treated by spinal irradiation for ankylosing spondilitis, and a group of Israeli children who received radiation treatment for thyroid disorders. Two groups of people who have been subjected to relatively large amounts of internal contamination are uranium miners and women who used radium paint in making luminous timepieces.

Table 3-10 summarizes health risk coefficients for whole body irradiation as estimated by four responsible organizations. The results, given by organ as well as the total for all fatal cancers, show the number of cancer deaths that can be expected in a population which receives a collective dose of one million rem. Although there are many differences in the numbers specified, the general trends are similar with the total number of cancer deaths ranging around 100 per million man-rem collective dose. The total number of 100 cancer deaths per million man-rem population exposure is also consistent with the estimated range of 68-119 absolute risk mortality as given by a preliminary release (later withdrawal) of the 1979 BEIR study results.[24]

One assumption is implicit in the presentation and use of data in the form shown in Table 3-10. This assumption is that health effects vary linearly with dose. This linearity assumption permits the application of this type of data to cumulated population dose since it makes no difference whether, for example, one person receives one rem or whether one thousand people each receive one millirem. The total health risk, in terms of the probability or number of latent cancer effects, is assumed to be the same.

The linearity assumption has been seriously questioned by several groups, including the National Council on Radiation Protection and Measurements (NCRP)[25] and the BEIR III dissenting group,[24] both of whom believe that this linearity assumption overestimates the health effects at low dose levels.

The coefficients of risk used herein for puposes of estimating cancer mortality and genetic detriment are listed in Table 3-11. These risk estimates are based on the values in Table 3-10 and are considered to be reasonable representations of the several sets of health risk data reviewed.

Table 3-10. Comparison of health risk estimates (tumor deaths or genetic defects) associated with collective dose of 10^6 organ-rem.

	BEIR-I [20]	UNSCEAR [21]	ICRP [22]	NRC [23]
Leukemia (red marrow)	20	20	20	28.4
Breast	45[a]	50	25	25.6
Lung	16-100[b]	25-50	20	22.2
Bone	2-17[b]	2-5	5	NS[c]
Liver	1-7[b]	10-15	NS	NS
Thyroid[d]	1.6-9.3[d]	10[e]	5[e]	4.3[f]
GI Tract[g]	30	10-15	NS	13.6
All Fatal Cancers	50-78[b,h] 92-165[b,i]	100	100	121.6
Genetic Defects	50-500[j,k] 10-100[j,l]	20-30[m] 185[n]	100[o]	95-165[p]

a. Derived from observed incidence in females by correcting for 50% cure rate and inclusion of males in population.

b. Lower value represents absolute risk model with 30 year plateau following latent period; higher value represents relative risk model with lifetime plateau.

c. NS-Not specified

d. Values represent incidence of thyroid cancers per year per 10^6 person-rem in irradiated children. The risk for adults is somewhat lower.

e. Mortality risk for general population.

f. Incidence of thyroid cancers per year per 10^6 person-rem in irradiated children and adults.

g. Includes stomach.

h. Based on atomic bomb survivor data.

i. Based on ankylosing spondilitis patient data.

j. Lower value assumes doubling dose of 200 rem, higher value assumes doubling dose of 20 rem.

k. Specific genetic defects including dominant, recessive and chromosomal diseases.

l. Defects with complex etiology including congenital anomalies, anomalies expressed later, constitutional and degenerative diseases.

m. Seriously affected cases per million liveborn.

n. Total detrimental genetic effects over all generations.

o. Serious hereditary ill health within the first two generations.

p. Total genetic disorders (autosomal dominant, multifactoral, chromosomal aberrations and spontaneous abortions) over all generations.

Table 3-11. Health risk coefficients used in this study

Organ	Tumor Deaths or Serious Genetic Defects per Million Organ-Rem
Marrow*	20
Breast	25**
Lungs	25
Liver	10
Thyroid	10
GI Tract	10
Total	100
Genetic Defects	100

* Leukemia
**Applied to total male plus female population

3.4.5 Sites

The population dose suffered after a release of radionuclides is dependent on several site-dependent factors including population, agriculture, and wind profile. Population doses at three sites were calculated. Two of these sites represent generic repository locations for the analysis of on-site sabotage consequences, and the third represents an urban location for the analysis of theft/sabotage consequences. The first site, the site of the proposed Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, was chosen as a generic desert location for a waste facility. The second site analyzed was the site used in the DOE Generic (waste repository) Environmental Impact Statement (GEIS)[5], and represents a site in a rural agricultural area near a population center. The third site analyzed is the urban location (on Long Island in New York City) analyzed by Sandia for a theft-sabotage release site. This third site is clearly not a potential repository site, but was analyzed as a worst case theft/sabotage release site. These sites are described in more detail below.

The WIPP Site

The site of the proposed Waste Isolation Pilot Plant (WIPP) in southeast New Mexico was chosen as a generic desert location for a waste facility. The description of this site was obtained from the draft environmental impact statement (DEIS) for the WIPP[4] and telephone conversations with one of the DEIS authors. The WIPP area is described as being semiarid with mild temperatures, with ranching being the characteristic activity. Typically, the land supports 6-9 cattle per square mile, but there are some irrigated areas along the Pecos River which support other feed crops (beans, pecans, peanuts, wheat, corn, barley, cotton) as well as increased cattle densities.

The WIPP site itself is described in the DEIS as having four control zones. Control Zone I, covering about 50 acres, contains most of the surface facilities and is surrounded by a security fence. Control Zone II, enclosing an area of about 1800 acres (nearly 3 square miles) will overlie the maximum extent of underground development. It will not be fenced except for two small plots set aside as long-term biological study plots. Livestock will be permitted within Zone II.

Control Zone III, surrounding Control Zone II, will have an outside diameter of about 4 miles and will enclose about 6200 acres. It also will not be fenced, and grazing will be permitted. With permission from DOE, shallow wells may be drilled for stock water, but no other drilling or mining will be permitted unless later evaluations show that such activities will not damage the repository.

Control Zone IV, surrounding Control Zone III, will have an outside diameter of 6 miles and an area of about 11,000 acres. Grazing and limited mining will be permitted in this area.

Table 3-12, taken from the WIPP DEIS, gives an estimated WIPP area population distribution for the year 2000. This population was estimated from the current population and growth rate for the area, with modification for impact due to construction and operation of the WIPP facility. The estimated population for year 2000 is about 250,000.

Table 3-13, derived from data in the WIPP DEIS, shows the annual average wind joint frequency distribution by direction, wind speed and stability class. These wind data, with one modification, were used for all WIPP site calculations reported herein. The modification made was that the worst case wind direction, toward Carlsbad (toward the west) was used. Note that the wind is in this direction (from the east) about 7% of the time. This worst case wind direction was used because it was assumed that a saboteur could coordinate the sabotage with wind direction. It was not assumed, however, that the saboteur could coordinate the sabotage with worst case wind speed or stability condition.

Figures 3-5 and 3-6, also taken from the WIPP DEIS, show the cultivated agricultural areas and cattle populations within fifty miles of the WIPP site. One percent of the cultivated land area shown in Figure 3-5 was assumed to be vegetable food crops. Table 3-14 shows other

Table 3-12. 2000 resident population within 50 miles of the reference site: Scenario II[a] (taken from WIPP DEIS)

	Miles from site						
Sector	0-5	5-10	10-20	20-30	30-40	40-50	Total
N	0	0	30	20	150	20	220
NNE	0	0	20	5	45	8,590	8,660
NE	0	0	0	20	60	9,490	9,570
ENE	0	0	10	60	165	53,390	53,610
E	0	0	5	15	4,965	135	5,120
ESE	0	0	5	10	4,665	240	4,920
SE	0	0	5	15	15	25	60
SSE	0	0	5	20	10	35	70
S	0	0	5	15	45	15	80
SSW	6	0	5	30	100	15	155
SW	0	5	60	15	10	50	140
WSW	0	0	2540	195	50	70	2,865
W	0	0	75	46,055	40	35	46,165
WNW	0	10	5	205	65	50	330
NW	0	0	30	20	70	14,860	14,980
NNW	0	0	15	5	260	5	285
Radius total	6	15	2815	46,705	10,715	87,025	147,280
Cumulative total	6	21	2835	49,555	60,255	147,280	---

[a] In scenario II, the distribution of direct and indirect impacts is assumed to be distributed as follows: Carlsbad, 54%; rest of Eddy County, 4%; Hobbs, 36%; rest of Lea County, 6%.

Table 3-13. WIPP Wind Frequency Data.

WIPP ANNUAL AVERAGE JOINT FREQUENCY DISTRIBUTION, PERCENT OF OCCURRENCE

WIND SPEED(M/S)	STABILITY TYPE	WIND DIRECTION N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1.50	A	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.00	0.00	0.10
3.00	A	0.40	0.10	0.20	0.20	0.30	0.70	1.20	1.10	1.50	0.70	0.50	0.50	0.40	0.40	0.40	0.30
5.00	A	0.40	0.20	0.10	0.20	0.30	0.40	1.20	2.50	2.00	0.50	0.60	0.70	0.60	0.30	0.40	0.30
8.00	A	0.30	0.10	0.20	0.10	0.10	0.10	0.30	0.50	0.20	0.10	0.20	0.60	1.20	0.20	0.20	0.20
10.40	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
13.60	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00
3.00	B	0.10	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10	0.10	0.10	0.10
5.00	B	0.10	0.00	0.10	0.10	0.10	0.10	0.10	0.30	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00
8.00	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
10.40	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.60	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00
3.00	C	0.00	0.10	0.00	0.10	0.00	0.00	0.10	0.20	0.30	0.10	0.10	0.10	0.10	0.10	0.10	0.10
5.00	C	0.00	0.00	0.00	0.10	0.00	0.00	0.10	0.20	0.20	0.00	0.00	0.00	0.10	0.10	0.00	0.00
8.00	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.40	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.60	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	D	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.20	0.10	0.10	0.10	0.20	0.10
3.00	D	0.30	0.20	0.20	0.20	0.10	0.50	0.90	0.80	0.60	0.50	0.20	0.20	0.30	0.20	0.20	0.30
5.00	D	0.10	0.30	0.20	0.40	0.30	0.30	0.50	0.50	0.40	0.10	0.10	0.00	0.20	0.00	0.10	0.10
8.00	D	0.10	0.10	0.10	0.20	0.30	0.00	0.10	0.10	0.00	0.00	0.10	0.10	0.20	0.00	0.10	0.10
10.40	D	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.60	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	E	0.20	0.10	0.10	0.10	0.20	0.20	0.30	0.20	0.30	0.10	0.10	0.10	0.10	0.10	0.20	0.10
3.00	E	0.10	0.20	0.30	0.50	0.50	0.90	2.00	1.00	0.70	0.20	0.10	0.10	0.20	0.10	0.20	0.20
5.00	E	0.20	0.10	0.30	0.30	0.80	0.80	2.20	1.40	0.20	0.00	0.00	0.20	0.30	0.10	0.10	0.20
8.00	E	0.20	0.00	0.00	0.20	0.60	0.10	0.50	0.50	0.00	0.00	0.00	0.00	0.20	0.10	0.10	0.00
10.40	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
13.60	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	F	0.20	0.20	0.40	0.50	0.40	0.60	0.70	0.40	0.20	0.10	0.10	0.00	0.10	0.10	0.10	0.10
3.00	F	0.20	0.20	0.20	0.30	0.30	0.80	2.00	1.00	0.10	0.10	0.10	0.20	0.20	0.10	0.10	0.20
5.00	F	0.10	0.00	0.00	0.10	0.20	0.00	0.20	0.30	0.10	0.10	0.10	0.10	0.20	0.10	0.00	0.00
8.00	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.40	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.60	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	G	0.50	0.30	0.80	1.50	1.10	2.00	2.60	0.80	0.50	0.30	0.20	0.20	0.10	0.10	0.20	0.30
3.00	G	0.50	0.50	1.30	1.10	1.00	1.10	1.80	0.60	0.20	0.10	0.20	0.30	0.30	0.20	0.20	0.20
5.00	G	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
8.00	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.40	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.60	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COLUMN TOTALS		4.10	2.90	4.60	6.60	7.00	8.90	17.90	12.70	8.00	3.40	3.10	4.00	5.30	2.60	3.20	3.00

TOTAL PERCENT FOR STABILITY CLASS

A	B	C	D	E	F	G
25.40	2.90	2.40	12.90	20.40	11.90	21.40

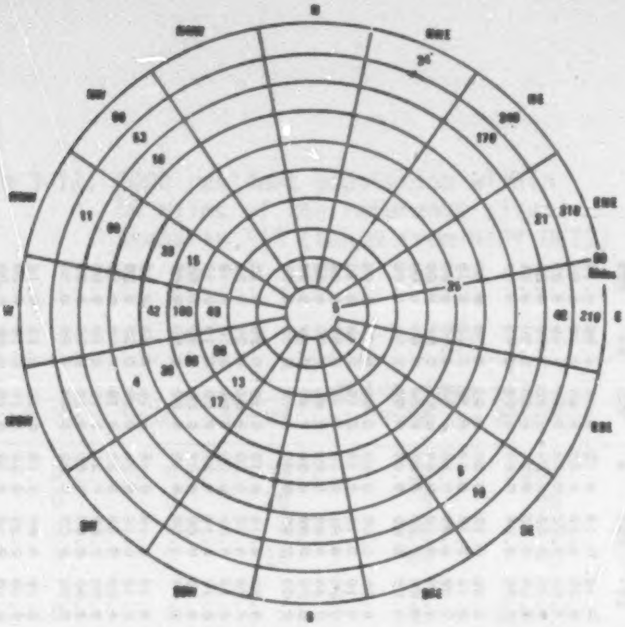

Figure 3-5. Agricultural areas. Values shown are millions of square meters cultivated in each sector. Shaded areas contain significant water, swimming might be possible in them.

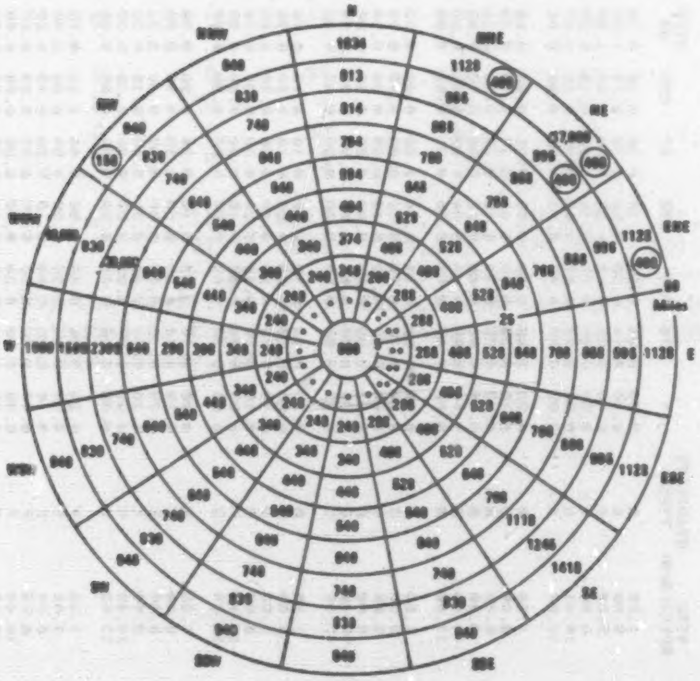

Figure 3-6. Beef cattle, sheep, and dairy cattle (circled) within 50 miles of the site.

Table 3-14. Miscellaneous data used in the AIRDOS-II calculation of population dose

Input Item	WIPP	GEIS	NYC
Height of plume lid, m	1,000	1,000	1,000
Rainfall rate, in/yr	0	0	0
Average air temperature, ^{o}K	288.6	289.1	289.1
Fraction of beef, milk, vegetables imported	0*	0*	1.0
Fraction of beef, milk, vegetables produced in 50 mile radius that is produced in section	1	1	n/a
Breathing rate, cm^3/hr	913,242	913,242	913,242
Fraction of time spent swimming	0	0	0
Buildup time for surface deposition, days	**	**	1
Length of cattle grazing season, days	365	365	n/a
Time from vegetable production to consumption, days	14	14	n/a
Time from beef production to consumption, days	20	20	n/a
Time from milk production to consumption, days	4	4	n/a
Vegetable food crop area to support one man, m^2	1,000	1,000	n/a
Pasture area per cow, m^2	121,410	10,000	n/a
Dry weight areal density of man's above surface food, kg/m^2	0.1	0.1	n/a
Dry weight areal grass density, kg/m^2	0.014	0.15	n/a
Depth of plow layer, cm	20	20	n/a
Dietary correction factor for above-surface food	0.25	0.25	n/a
Dietary correction factor for uptake from soil	1.	1.	n/a
Dietary correction factor for beef	1.	1.	n/a
Dietary correction factor for milk	1.	1.	n/a

* These values were changed to 1.0 for food interdiction cases.

**Values used were 365 for 1 year doses, 1.0 for 24-hour doses, and .08333 for 2-hour doses.

Table 3-14. Miscellaneous data used in the AIRDOS-II calculation of population dose (continued)

Input Item	WIPP	GEIS	NYC
Rate of increase of steer muscle mass, kg/day	0.4	0.4	n/a
Steer muscle mass at slaughter, kg	200	200	n/a
Soil density, gm/cm^3	1.4	1.4	n/a
Fallout correction factor for above-surface food	0.1	0.1	n/a
Fallout correction factor for soil surface below food	0.9	0.9	n/a
Fallout correction factor for pasture grass	0.0233	0.25	n/a
Fraction of beef herd slaughtered per day, day^{-1}	0.004	0.004	n/a
Number of milkings per cow, day^{-1}	2.0	2.0	n/a
Beef consumption per man, kg/day	0.8	0.315	n/a
Milk consumption per man, liters/day	1.0	0.175	n/a
Transfer rate - above-surface food to soil surface, day^{-1}	0.0495	0.0495	n/a
Transfer rate - pasture grass to pasture soil, day^{-1}	0.0495	0.0495	n/a
Transfer rate - soil pool to soil sink, day^{-1}	0.0001096	0.0001096	n/a
Transfer rate - pasture soil to soil sink, day^{-1}	0.0001096	0.0001096	n/a
Transfer rate - pasture soil to pasture grass, day^{-1}	0.0000274	0.0000274	n/a
Transfer rate - soil surface to soil pool, day^{-1}	0.000693	0.000693	n/a
Milk capacity of the udder, liters	5.5	5.5	n/a
Vegetable food consumption of man, kg/day	0.25	0.30	n/a
Dry grass consumption of cow, kg/day	10	10	n/a
Milk production of cow, liters/day	11	11	n/a

miscellaneous data used in the AIRDOS-II analysis of population exposure for the WIPP, GEIS and urban sites. The data in Table 3-14 were gathered from several sources, including ORNL-4992,[26] NRC Regulation 1.109,[19] and the WIPP DEIS [4].

A few additional words of explanation on a few data items in Table 3-14 are worthwhile. First, a zero rainfall rate was assumed for all three sites, based on the assumption that the sabotage would occur during dry weather. It is possible that more severe radiological consequences might occur in rainy weather. Steady rainfall conditions will increase the local deposition rate, thus causing higher radionuclide depositions near the release site and lower depositions farther away. The worst case condition would be for no rain until the cloud of nuclides reached a population area, at which point it would start to rain. Rainfall conditions were not analyzed.

Two food consumption conditions were analyzed: no interdiction of contaminated food; and 100% interdiction of contaminated food. This condition was controlled by the input variables which specified the fraction of beef, vegetables and milk imported into the analysis area. An input fraction of 0 corresponded to no food interdiction, and an input fraction of 1.0 corresponded to complete food interdiction. Off-line food balances were performed for the GEIS and WIPP sites to assure that food consumption in the analysis area would balance the food production. The result was the rather high milk and beef consumption rates specified for the WIPP area (1 liter/day and 0.8 kg/day, respectively) to assure that all contaminated foods were accounted for.

The GEIS Site

The second site analyzed was the site used in the DOE Generic waste repository Environmental Impact Statement (GEIS). This site represents a rural site in an agricultural area near a population center. The description of this site was obtained largely from the DOE GEIS.[5]

The total population for the 50-mile radius GEIS analysis area is about 2,000,000, most of whom live in a city of 1,800,000 people about 50 km SE of the GEIS site. The population distribution for the GEIS analysis area, taken from the GEIS, is given in Table 3-15.

Table 3-16, also from the GEIS, gives the annual average wind joint frequency distribution by direction, wind speed and stability class. These wind data were used in the GEIS analyses reported herein with the modification that the worst case wind direction, toward the SE, was always used. (Note: the wind is in this direction about 11% of the time.)

The GEIS site has already been described as lying in an agricultural area; however, the chief crops in the area (soybeans, hay, corn, oats) are used for livestock feed and are not usually consumed directly by humans. For the purpose of GEIS site analysis, the local agriculture was assumed to be characterized as follows:

- vegetable food crops - 1% of the land area
- beef cattle - 80 per square mile
- milk cows - 3 per square mile

The Urban Site

The New York City urban area analyzed was, of course, not representative of a candidate repository area, but represented a severe (if not worst) case area for a theft/sabotage release event. The New York City area was selected largely because of the availability of data -- it had recently been used by Sandia for calculation of sabotage/theft consequence relative to nuclear spent fuel transport.[7]

Figure 3-7 shows the location in NYC where the release was assumed to occur. The assumed release location is on the west end of Long Island, about 7 km from LaGuardia airport and about 10 km from JFK International Airport.

Table 3-15. Projected year 2000 population in reference GEIS environment

RANGE, km	1.6	3.2	4.8	6.4	8.0	16	32	48	64	80	TOTALS
N	0	4	4	18	160	210	1,115	3,641	2,137	1,209	8,498
NNE	0	4	4	14	26	157	986	3,350	4,185	1,872	10,598
NE	0	6	18	72	109	232	1,306	4,897	2,848	6,371	15,859
ENE	0	4	12	72	145	333	2,025	2,677	8,743	6,209	20,220
E	0	4	12	145	537	993	1,321	9,094	6,344	14,195	32,645
ESE	0	4	20	353	118	610	3,400	50,482	123,104	163,155	341,246
SE	0	25	245	1,069	194	632	5,063	46,789	581,389	579,114	1,214,520
SSE	0	4	18	45	157	374	3,466	18,642	59,435	32,445	114,586
S	0	4	41	67	112	1,097	5,438	5,844	10,131	7,334	30,068
SSW	0	15	26	67	126	571	3,177	4,809	6,411	7,317	22,523
SW	0	30	65	58	50	423	1,835	4,656	6,106	6,856	20,079
WSW	0	6	55	93	65	414	3,007	1,901	7,515	4,442	17,498
W	0	9	31	78	73	379	1,730	3,600	3,326	4,805	14,031
WNW	4	8	8	44	29	332	1,662	6,495	6,493	5,984	21,059
NW	0	6	9	21	44	293	5,277	47,196	4,061	4,501	61,408
NNW	0	8	15	55	181	165	1,204	2,753	2,480	4,533	11,394
TOTALS	8	141	583	2,271	2,126	7,215	42,012	216,826	834,708	850,342	1,956,232
CUM TOTL (rounded)	8	150	730	3,000	5,100	12,000	54,000	270,000	1,100 000	2,000,000	2,000,000

Table 3-16. Annual Average Joint GEIS Wind Frequency Distribution, Percent of Occurrence.

GEIS ANNUAL AVERAGE JOINT FREQUENCY DISTRIBUTION, PERCENT OF OCCURRENCE

WIND SPEED(M/S)	STABILITY TYPE	WIND DIRECTION N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1.10	A	0.00	0.02	0.00	0.01	0.00	0.01	0.01	0.00	0.02	0.02	0.00	0.00	0.01	0.02	0.00	0.00
2.50	A	0.26	0.10	0.11	0.17	0.12	0.07	0.15	0.11	0.15	0.25	0.21	0.31	0.35	0.32	0.37	0.19
4.30	A	0.58	0.27	0.31	0.21	0.22	0.22	0.30	0.47	0.58	0.40	0.58	0.42	0.41	0.62	0.77	0.62
6.50	A	0.16	0.06	0.07	0.01	0.06	0.25	0.72	0.73	1.38	0.62	0.16	0.15	0.09	0.51	0.64	0.59
9.10	A	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.32	0.31	0.07	0.00	0.04	0.04	0.10	0.17	0.14
12.20	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.10	B	0.00	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.06	0.01	0.04	0.04	0.01	0.00	0.01	0.00
2.50	B	0.16	0.09	0.04	0.16	0.05	0.12	0.09	0.06	0.15	0.11	0.14	0.12	0.16	0.14	0.16	0.10
4.30	B	0.12	0.19	0.14	0.05	0.14	0.05	0.09	0.14	0.23	0.21	0.19	0.07	0.23	0.16	0.22	0.22
6.50	B	0.05	0.01	0.01	0.02	0.01	0.07	0.07	0.05	0.07	0.02	0.00	0.00	0.06	0.21	0.21	0.17
9.10	B	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.00	0.11	0.01
12.20	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.10	C	0.04	0.02	0.01	0.04	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.05	0.01	0.02	0.00	0.00
2.50	C	0.02	0.05	0.10	0.04	0.06	0.07	0.07	0.06	0.06	0.12	0.06	0.09	0.10	0.07	0.09	0.09
4.30	C	0.10	0.11	0.04	0.07	0.04	0.07	0.05	0.17	0.12	0.05	0.04	0.02	0.16	0.17	0.22	0.14
6.50	C	0.06	0.02	0.01	0.04	0.01	0.04	0.05	0.04	0.07	0.01	0.01	0.02	0.00	0.17	0.15	0.07
9.10	C	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.02	0.02	0.07	0.00
12.20	C	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.10	D	0.23	0.19	0.16	0.22	0.04	0.07	0.09	0.07	0.10	0.10	0.14	0.10	0.11	0.07	0.10	0.09
2.50	D	0.68	0.54	0.61	0.85	0.82	0.47	0.46	0.47	0.53	0.32	0.32	0.41	0.67	0.47	0.99	0.90
4.30	D	0.78	0.73	0.64	0.62	1.03	0.94	1.17	0.90	0.86	0.49	0.36	0.36	0.72	1.30	1.65	1.30
6.50	D	0.73	0.21	0.27	0.19	0.46	0.61	0.61	0.37	0.35	0.20	0.22	0.16	0.38	1.24	1.40	0.78
9.10	D	0.02	0.10	0.04	0.00	0.00	0.01	0.04	0.07	0.05	0.02	0.01	0.01	0.16	0.07	0.21	0.10
12.20	D	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00
1.10	E	0.09	0.06	0.02	0.11	0.15	0.07	0.20	0.09	0.14	0.11	0.10	0.10	0.12	0.05	0.17	0.06
2.50	E	0.57	0.51	0.35	0.25	0.61	0.57	0.72	0.33	0.30	0.21	0.42	0.52	0.65	0.49	0.75	0.48
4.30	E	0.22	0.27	0.10	0.06	0.38	0.26	0.91	0.69	1.16	0.57	0.49	0.30	0.67	0.64	0.78	0.35
6.50	E	0.10	0.01	0.00	0.00	0.11	0.01	0.15	0.30	0.56	0.30	0.10	0.06	0.05	0.22	0.09	0.02
9.10	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.20	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.10	F	0.15	0.07	0.11	0.11	0.10	0.12	0.06	0.12	0.19	0.10	0.15	0.15	0.21	0.09	0.10	0.20
2.50	F	0.25	0.14	0.22	0.15	0.42	0.40	0.46	0.58	0.65	0.32	0.35	0.35	0.63	0.37	0.67	0.38
4.30	F	0.01	0.00	0.01	0.00	0.02	0.05	0.20	0.30	0.48	0.27	0.14	0.05	0.10	0.04	0.17	0.14
6.50	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.05	0.00	0.00	0.01	0.00	0.00	0.00
9.10	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.20	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.10	G	0.11	0.08	0.04	0.12	0.20	0.11	0.19	0.32	0.31	0.17	0.31	0.46	0.33	0.22	0.20	0.12
2.50	G	0.11	0.05	0.05	0.07	0.14	0.17	0.32	0.63	0.74	0.21	0.23	0.28	0.28	0.15	0.35	0.36
4.30	G	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.16	0.02	0.00	0.02	0.01	0.00	0.12	0.04
6.50	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.10	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.20	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COLUMN TOTALS		5.63	4.01	3.49	3.59	5.24	4.87	7.24	7.53	10.07	5.37	4.77	4.67	6.76	7.95	10.95	7.66

TOTAL PERCENT FOR STABILITY CLASS	A	B	C	D	E	F	G
	17.83	5.84	3.92	34.39	19.47	10.46	7.89

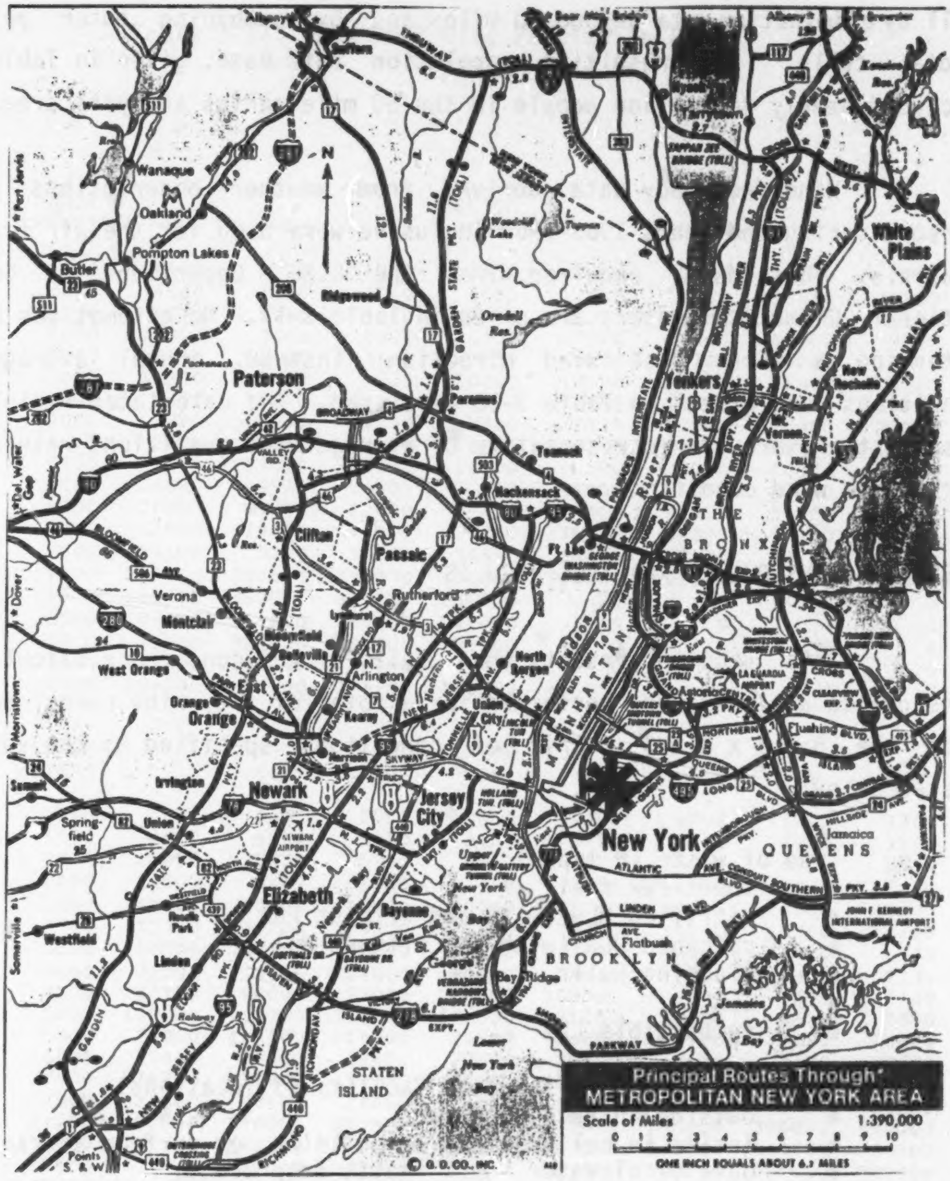

Figure 3-7. Map showing assumed release location in New York City

READEX FICHE

The population data used by Sandia for computer program CRAC analyses was acquired from Sandia and was reduced from the 16 direction x 34 radial cell CRAC format to the AIRDOS-II limit of 16 directions x 20 radial cell by eliminating data beyond 50 miles and by combining outer pairs of radial cells. The resulting population data base, given in Table 3-16, included nearly 40 million people in the 50 mile radius analysis area.

Wind frequency data derived from weather observations at JFK Airport during the years 1965-1969 inclusive were used for the air transport analysis. These data, acquired from the U.S. Department of Commerce National Climatic Center, are given in Table 3-17. No attempt was made to determine a worst case wind direction; instead, annual average wind conditions as given in Table 3-18 were used. The calculated radiological results therefore are representative of average wind conditions rather than worst case wind conditions.

3.5 CONSEQUENCE ANALYSES RESULTS

This section presents the results of the conseqence calculations. Consequence analyses were performed for a total of fity-nine cases selected from the 8 x 3 x 3 x 3 matrix of conditions specified by the variables listed below:

- Type of waste (8 types)
  - spent PWR fuel
  - vitrified HLW (with and without Pu)
  - calcined HLW (with and without Pu)
  - cladding hulls
  - ILW
  - combustible LLW

- Location of release in waste facility (3 locations)
  - outside in receiving yard
  - inside in cell, unloading building, or surface storage facility
  - base of elevator shaft (hoist drop event)

- Facility (3 sites)
  - generic desert site (WIPP)
  - generic rural site (GEIS)
  - urban site for theft/sabotage dispersal (NYC)

- Calculation type (3 calculations)
  - population dose
    - 365-day cumulated exposure with no evacuation or food interdiction

Table 3-17. New York City Population Data.

RANGE				SECTOR				
METERS	N	NNE	NE	ENE	E	ESE	SE	SSE
500	1520	1520	1520	1520	2170	2170	2170	2170
1000	4560	4560	4560	4560	6510	6510	6510	6510
1500	7590	1910	1910	2210	5390	10400	10400	6190
2000	10700	2680	2680	3100	7570	14600	14600	8700
2500	10800	3440	3440	8730	10800	18700	18700	11600
3000	13300	9400	9400	10700	13200	16400	16400	14200
3500	6830	11100	11100	6380	7910	19400	19400	23400
4000	7880	12800	12800	7360	9130	22400	22400	27000
4500	8920	12100	12100	10300	9340	21500	21500	19100
5000	9980	13500	13500	11600	10500	24000	24000	21400
5500	26800	14900	14900	26800	26800	26600	26600	26800
6000	29400	12900	12900	29400	29400	31500	31500	20400
7000	31900	14000	14000	31900	31900	34300	34300	31900
7500	34600	15200	15200	34600	34600	37100	37100	34600
11200	390000	390000	390000	390000	390000	390000	390000	390000
16000	660000	660000	660000	660000	0	0	0	0
32000	589000	589000	589000	589000	0	0	0	0
48000	981000	981000	981000	981000	0	0	0	0
64000	137400	137400	137400	137400	0	0	0	0
80000	176700	176700	176700	176700	0	0	0	0

RANGE				SECTOR				
METERS	S	SSW	SW	WSW	W	WNW	NW	NNW
500	2050	2050	2050	2050	1300	1300	1300	1300
1000	6150	6150	6150	6150	3910	3910	3910	3910
1500	11000	5950	5950	4560	6030	6030	6030	6890
2000	15500	8360	8360	6400	8460	6030	6030	9670
2500	10600	10700	10700	62500	60700	10900	10900	13600
3000	12900	40200	40200	76600	74300	14300	14300	16700
3500	19800	47500	47500	77100	74600	16800	16800	6700
4000	22900	54800	54800	88900	86000	19400	19400	7730
4500	97100	92000	92000	104000	108000	7340	7340	8760
5000	109000	103000	103000	116000	121000	8200	8200	9800
5500	26800	114000	114000	26800	26800	9100	9100	26800
6000	29400	29400	29400	29400	29400	3680	3680	29400
7000	31900	31900	31900	31900	31900	40100	40100	31900
7500	34600	34600	34600	34600	34600	43400	43400	34600
11200	390000	390000	390000	390000	390000	390000	390000	390000
16000	0	660000	660000	660000	660000	660000	660000	660000
32000	0	589000	589000	589000	589000	589000	589000	589000
48000	0	981000	981000	981000	981000	981000	981000	981000
64000	0	137400	137400	137400	137400	137400	137400	137400
80000	0	176700	176700	176700	176700	176700	176700	176700

Table 3-18. New York City Wind Frequency Data.

JFK ANNUAL AVERAGE JOINT FREQUENCY DISTRIBUTION, PERCENT OF OCCURRENCE

WIND SPEED(M/S)	STABILITY TYPE	WIND DIRECTION N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1.80	A	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
3.30	A	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
5.40	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.50	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.80	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.40	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.80	B	0.01	0.04	0.05	0.04	0.04	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.02	0.01	0.01
3.30	B	0.12	0.07	0.06	0.05	0.07	0.03	0.01	0.01	0.11	0.03	0.09	0.04	0.05	0.04	0.04	0.05
5.40	B	0.06	0.05	0.05	0.03	0.02	0.01	0.03	0.03	0.29	0.07	0.12	0.09	0.09	0.03	0.06	0.05
8.50	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.80	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.40	B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.80	C	0.00	0.01	0.02	0.02	0.04	0.01	0.02	0.01	0.03	0.03	0.01	0.00	0.02	0.01	0.00	0.00
3.30	C	0.19	0.08	0.10	0.13	0.11	0.06	0.05	0.03	0.12	0.08	0.12	0.27	0.13	0.01	0.06	0.10
5.40	C	0.50	0.36	0.21	0.18	0.17	0.08	0.20	0.31	1.61	0.58	0.66	0.82	0.53	0.18	0.29	0.33
8.50	C	0.09	0.06	0.03	0.00	0.01	0.06	0.06	0.14	1.04	0.14	0.10	0.07	0.12	0.05	0.10	0.04
10.80	C	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.08	0.01	0.01	0.00	0.00	0.00	0.01	0.01
15.40	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.80	D	0.03	0.01	0.05	0.08	0.11	0.09	0.05	0.06	0.11	0.06	0.05	0.05	0.02	0.00	0.02	0.02
3.30	D	0.24	0.27	0.38	0.45	0.68	0.31	0.39	0.27	0.66	0.31	0.33	0.40	0.24	0.08	0.12	0.11
5.40	D	1.51	1.20	1.17	1.22	1.18	0.81	0.86	0.72	2.79	1.58	1.44	1.90	1.48	0.67	0.78	0.80
8.50	D	2.90	1.20	1.16	0.74	0.96	0.63	0.60	0.56	4.12	1.75	1.00	1.66	2.97	2.38	3.69	2.56
10.80	D	0.57	0.17	0.20	0.21	0.28	0.11	0.10	0.08	1.09	0.49	0.10	0.20	1.12	0.99	1.51	0.64
15.40	D	0.16	0.05	0.08	0.03	0.10	0.02	0.01	0.02	0.18	0.07	0.03	0.05	0.44	0.29	0.53	0.13
1.80	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.30	E	0.18	0.16	0.29	0.31	0.40	0.18	0.16	0.16	0.56	0.42	0.54	0.48	0.23	0.11	0.12	0.14
5.40	E	1.05	0.55	0.31	0.14	0.08	0.08	0.08	0.13	0.69	0.73	0.77	1.16	0.98	0.65	0.98	0.86
8.50	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.80	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.40	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.80	F	0.11	0.07	0.09	0.21	0.26	0.14	0.06	0.07	0.20	0.10	0.10	0.14	0.15	0.09	0.06	0.08
3.30	F	0.48	0.33	0.49	0.43	0.37	0.14	0.18	0.13	0.39	0.34	0.50	0.64	0.60	0.28	0.27	0.17
5.40	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.50	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.80	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.40	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.80	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.30	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.40	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.50	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.80	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.40	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COLUMN TOTALS		8.22	4.69	4.78	4.27	4.87	2.78	2.90	2.77	14.09	6.80	5.99	8.00	9.21	5.87	8.64	6.12

TOTAL PERCENT FOR STABILITY CLASS	A	B	C	D	E	F	G
	0.05	2.36	11.16	65.07	13.68	7.68	0.00

- 24-hour exposure with total food interdiction
- maximum individual dose at site boundary
- 2-hour exposure with total food interdiction

Eight fuel types were analyzed. These cover the LWR fuel cycles anticipated, i.e., once through spent fuel without processing, UO_2 only recycle, and UO_2 and PuO_2 recycle. Two types of HLW were considered: 1) vitrified, which is the reference form[5] and 2) calcined HLW, as a well-developed alternative.[5] There are several types of calcined waste. Spray calcined, which has the smallest particle size, was assumed as a worst case condition. Cladding hulls were assumed to be stored with sand in canisters. ILW was assumed to be stabilized in concrete and sealed in drums. Combustible LLW, including rags, discarded clothing, filters, etc. was assumed to be sealed in drums. Separated PuO_2 was not considered here; separated PuO_2 was assumed to be stored elsewhere.

The locations of the release event in the facility, the reason for their selection, and the three sites analyzed for the release event were described earlier in this chapter. Figure 3-8 shows in matrix form the cases analyzed for the eight waste types, three sites and three locations in the facility considered. Consequences were calculated for yard releases resulting from sabotage of spent fuel and HLW casks, but consequences were not calculated for receiving yard attacks or ILW, cladding hull or LLW containers because prior screening had indicated that the consequences for the latter cases would be much less than the consequences for other cases.

As noted in Figure 3-8, releases from sabotage events in the receiving yard were ground level releases. Releases within the surface or subsurface portions of the facility resulted in stack releases. The stack height assumed was 110 meters, per Reference 5.

Three sets of calculations were performed for the matrix of cases shown in Figure 3-8, including two calculations of population dose and one calculation of site boundary maximum individual dose. One calculation of population dose was performed to determine the dose and latent cancer fatalities (LCF's) which would occur if there were no evacuation and no food interdiction, while the other calculation of population dose was performed

KEY:
W = WIPP SITE
G = GEIS SITE
N = URBAN SITE (NYC)*

	LOCATION OF SABOTAGE EVENT		
	SURFACE LEVEL		MINE LEVEL
WASTE TYPE	YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
SPENT FUEL	W, G, N	W, G	W, G
VITRIFIED HLW W/O PU	W, G, N	W, G	W, G
VITRIFIED HLW W PU	W, G, N	W, G	W, G
CALCINED HLW W/O PU	W, G, N	W, G	W, G
CALCINED HLW W PU	W, G, N	W, G	W, G
CLADDING HULLS		W, G	
ILW		W, G	
LLW-COMBUSTIBLE		W, G	
	GROUND LEVEL RELEASE	STACK RELEASE	

*24 HOUR DOSE W/O INGESTION CASES ONLY.

Figure 3-8. Matrix of release events analyzed

to determine the exposure with evacuation and with food interdiction. For the case with no evacuation and no food interdiction, surface exposure doses were cumulated over 365 days, and all exposure pathways, discussed earlier herein were treated. For the case with evacuation and total food interdiction, the average evacuation time was assumed to be 24 hours. Thus surface exposure was cumulated for 24 hours. The other pathways considered were inhalation and air immersion.

The site boundary dose calculation was performed to determine the maximum dose which could occur to an off-site individual. The site boundary was assumed to be a distance of 250 meters* from the release point (approximate radius of the WIPP site's fenced control zone I[4]). Total body doses for a 2-hour exposure time were calculated for comparison with the 25-rem site boundary total boundary dose as specified by 10 CFR 100.11[27] for nuclear reactor sites.

3.5.1 Site Boundary Doses

Figure 3-9 gives the site boundary doses calculated for the WIPP and GEIS sites, the eight waste forms and three release locations. The numbers to the left of the slashes (/) are the values for the WIPP site and the numbers on the right of the slashes are for the GEIS site. The GEIS doses are generally about 20% higher than the WIPP boundary doses, a difference caused by the slight difference in site wind distributions.

Note that the doses shown here include the total external dose from air immersion in the passing puff of airborne contamination, the total internal dose (50-year commitment) from inhalation, and the two-hour time integrated dose from surface exposure. No exposure from contaminated food was considered.

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* For stack releases, it was found that doses were higher at 450-550 meters than at 250 meters from the release point. For those cases, the dose at the maximum dose location was calculated.

WASTE TYPE	LOCATION OF SABOTAGE EVENT		
	SURFACE LEVEL		MINE LEVEL
	YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
SPENT FUEL	100/120	0.1/0.1	0.2/0.2
VITRIFIED HLW W/O PU	160/200	1.0/1.2	2.0/2.3
VITRIFIED HLW W PU	2000/2400	12/15	24/28
CALCINED HLW W/O PU	2200/2600	19/22	17/20
CALCINED HLW W PU	27000/32000	220/280	200/240
CLADDING HULLS		0.01/0.01	
ILW		<0.001/<0.001	
LLW-COMBUSTIBLE		0.003/0.004	
	GROUND LEVEL RELEASE	STACK RELEASE	

Figure 3-9. Maximum individual total body dose (Rem) at site boundary, WIPP/GEIS sites

There is a rather considerable difference in site boundary dose between the "yard" release events and the "surface facility" release events. These differences are caused primarily by effects of the 110-meter stack, which very substantially reduce doses close to the facility.

These results indicate that the 25 rem site boundary total body dose limit would be exceeded for all the outside sabotage events considered for spent fuel and HLW, and for all inside-facility sabotage events considered for calcined HLW with Pu.

3.5.2 Population Effects for 24-Hour Evacuation and Total Food Interdiction

Figures 3-10 and 3-11 give the population latent cancer fatalities (LCF's) and genetic defects calculated for the evacuation and total food intediction condition. Data for the three sites considered, WIPP, GEIS and urban (NYC) are separated by slashes.

The data includes some large numbers of LCF's and genetic defects, the largest of which are one hundred thousand LCF's and one hundred sixty thousand genetic defects for the theft/sabotage release of calcined HLW with Pu in New York City. The consequences for sabotage of a calcined HLW canister at the desert (WIPP) facility are also large, with about two hundred fifty LCF's occurring for that case.

The consequences are much less for release of more reasonable waste types, i.e., spent fuel or vitrified HLW without Pu, in a less populated area. The maximum number of LCF's for spent fuel or vitrified HLW without Pu for the WIPP site was 3.

The consequences for sabotage of LLW, ILW or cladding hulls were found to be relatively small, with less than one LCF expected for each of the LLW, ILW or cladding hulls events calculated.

Comparison of the LCF's for the different sites indicates that the LCF's for the GEIS site are a factor of 10-15 greater and the LCF's for the NYC release area are a about factor of 400 greater than for the WIPP site.

	LOCATION OF SABOTAGE EVENT		
	SURFACE LEVEL		MINE LEVEL
WASTE TYPE	YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
SPENT FUEL	0.8/9/300	0.3/3.5	0.4/5
VITRIFIED HLW W/O PU	0.7/8/280	1.6/22	3/44
VITRIFIED HLW W PU	19/210/7000	41/570	81/1100
CALCINED HLW W/O PU	10/110/3700	30/420	27/370
CALCINED HLW W PU	250/2800/94000	780/11,000	680/9300
CLADDING HULLS		0.04/0.5	
ILW		<0.001/0.006	
LLW-COMBUSTIBLE		0.01/0.2	
	GROUND LEVEL RELEASE	STACK RELEASE	

NOTE: Estimated one-sigma uncertainty is ± a factor of 11 for spent fuel and ± a factor of 15 for other waste forms.

Figure 3-10. Population late fatalities, WIPP/GEIS/NYC sites, 24-hour exposure (50-year commitment) w/o ingestion

		LOCATION OF SABOTAGE EVENT		
		SURFACE LEVEL		MINE LEVEL
		YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
WASTE TYPE	SPENT FUEL	2/15/500	0.4/6	0.6/9
	VITRIFIED HLW W/O PU	1/13/450	3/36	5/69
	VITRIFIED HLW W PU	32/360/12000	70/1000	140/2000
	CALCINED HLW W/O PU	16/180/6000	50/660	43/580
	CALCINED HLW W PU	430/4900/160000	1300/18000	1200/16000
	CLADDING HULLS		0.06/0.8	
	ILW		<0.001/0.01	
	LLW-COMBUSTIBLE		0.02/0.3	
		GROUND LEVEL RELEASE	STACK RELEASE	

NOTE: Estimated one-sigma uncertainty is ± a factor of 11 for spent fuel and ± a factor of 15 for other waste forms.

Figure 3-11. Population genetic defects WIPP/GEIS/NYC sites (24-hour exposure (50-year commitment) w/o ingestion)

The major reason for these differences is the difference in population density within a few km of the release location.

It is of interest to compare the LCF's calculated herein for the spent fuel/NYC case with results for a similar case calculated by Sandia as reported in Reference 7. Sandia used the CRAC and METRAN computer codes to calculate the LCF's for a release from a 3 fuel element truck cask, and used the CRAC code to calculate LCF's for a release from a 10-fuel element rail cask. They treated release fractions parametrically; one of their sets of release parameters, 10% noble gas release, and 0.07% particulate release, are the same as the release fractions assumed herein. They applied these release fractions to the total cask inventory to determine how much material became airborne, but the METRAN and CRAC codes used built-in factors to determine what fraction of this release is respirable (100% of the release was assumed herein to be respirable).

Their METRAN results for the 3-element cask case showed several tens of LCF's (range from 16-320 and mean of 63 reported, depending on release location and time of day) for detailed analysis of a 10 x 10 km area. The same case, including the same area, was run on CRAC; and factor-of-2 agreement was obtained. The CRAC analysis area was then expanded from the 10x10 mile area to the 500 mile area, and it was found that most (approximately 60%) of the LCF's occurred inside the 10 x 10 km area, thus substantiating the METRAN results for the smaller area.

The value of 300 LCF's given herein is about a factor of five higher than Sandia's mean value of 63 LCF's, which probably represents their most comparable case. The major causes of this difference are expected to be inherent shielding in the city (due to large buildings, etc.), and the respirable particle size factor, each of which could affect the result by a factor of three.

It is also of interest to derive the breakdown in contribution to the number of LCF's i.e., principal pathway, isotope and organ contributors. Because of the detail involved, this breakdown is reported herein for only one case. The case for this detailed analysis was selected from cases reported in the next section, where the ingestion pathway was included.

3.5.3 Population Effects For No Food Interdiction or Evacuation

Figures 3-12 and 3-13 give the population LCF's and genetic defects calculated for the (admittedly unrealistic) condition in which there was no population evacuation or food interdiction. Because of the additional surface exposure time (365 days vs 24 hours) and added ingestion pathway, the numbers are higher than those for corresponding cases reported in Figures 3-10 and 3-11. For spent fuel and HLW with Pu, the LCF's are increased by amounts ranging from 10% to 100%, but for HLW without Pu, the LCF's are increased by a factor of 3 to 9. For spent fuel and HLW with Pu, the LCF's are controlled by inhalation of actinides while for HLW without Pu, ingestion of cesium and strontium is of major importance.

As mentioned earlier, one case was selected for a more detailed analysis. This case was the spent fuel yard release case for the WIPP facility, for which there were 1.2 LCF's.

Table 3-19 shows the total dose for the various body organs and the corresponding contribution to LCF's. The primary organ cancer contributors are leukemia, resulting from marrow dose, and breast cancer, resulting from breast dose (breast dose and muscle dose were assumed to be the same).

Table 3-20 shows the pathway contributors to the various organ doses. The principal pathway contributor to bone/marrow and muscle is inhalation, which contributes approximately 70% of the dose to those organs.

Table 3-21 shows the radionuclide contributors to the various organ doses. The principal radionuclide contributors to the bone/marrow and muscle doses are Sr-90, Pu-238 and Pu-241.

		LOCATION OF SABOTAGE EVENT		
		SURFACE LEVEL		MINE LEVEL
		YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
WASTE TYPE	SPENT FUEL	1/19	0.4/8	0.5/11
	VITRIFIED HLW W/O PU	2.5/73	6/190	11/380
	VITRIFIED HLW W PU	21/280	45/740	89/1400
	CALCINED HLW W/O PU	34/970	110/3600	92/3200
	CALCINED HLW W PU	270/3700	850/14000	75/12000
	CLADDING HULLS		0.07/1.2	
	ILW		0.002/0.06	
	LLW-COMBUSTIBLE		0.01/0.2	
		GROUND LEVEL RELEASE	STACK RELEASE	

NOTE: Estimated one-sigma uncertainty is ± a factor of 11 for spent fuel and ± a factor of 15 for other waste forms.

Figure 3-12. Population late fatalities, WIPP/GEIS sites, 365-day exposure (50-year commitment) with ingestion, no evacuation or food interdiction

WASTE TYPE	LOCATION OF SABOTAGE EVENT		
	SURFACE LEVEL		MINE LEVEL
	YARD	SURFACE FACILITY	BOTTOM OF ELEVATOR SHAFT
SPENT FUEL	2/31	0.6/12	1/18
VITRIFIED HLW W/O PU	4/110	8/290	16/570
VITRIFIED HLW W PU	35/460	77/1200	150/2400
CALCINED HLW W/O PU	50/1500	160/5500	140/4800
CALCINED HLW W PU	460/6200	1400/23000	1300/20000
CLADDING HULLS		0.08/2	
ILW		0.003/0.1	
LLW-COMBUSTIBLE		0.02/0.3	
	GROUND LEVEL RELEASE	STACK RELEASE	

NOTE: Estimated one-sigma uncertainty is ± a factor of 11 for spent fuel and ± a factor of 15 for other waste forms.

Figure 3-13. Population genetic defects WIPP/GEIS sites (365-day exposure (50-year commitment) no evacuation or food interdiction)

Table 3-19. Sample result, WIPP site -- ten spent fuel elements in cask, ground level release outside

ORGAN	DOSE (MAN-REM)		EFFECTS/10^6 ORGAN-REM	EFFECTS	
TOT. BODY	2.3×10^3		--	--	
GI TRACT	1.5×10^3		10	0.02	
MARROW	1.9×10^4		20	0.38	
THYROID	1.9×10^4		10	0.19	
LUNGS	1.2×10^3		25	0.03	
MUSCLE*	1.9×10^4		25	0.43	
KIDNEYS	7.8×10^3		--	0.048	
LIVER	8.2×10^3		10	0.08	
SPLEEN	1.9×10^4		--	--	
		TOTAL	100	1.2	LATE FATALITIES
TESTES	1.9×10^4		100	1.9	GENETIC DEFECTS
OVARIES	1.9×10^4				

---

*MUSCLE DOSE ASSUMED SAME AS BREAST DOSE

Table 3-20. Contribution by exposure pathway to various organ total doses, spent fuel/yard release case, WIPP site. Table gives percent of organ dose by exposure pathway (values less than 0.5% are shown as zero).

PATHWAY	GI TRACT	BONE/MARROW	THYROID	LUNGS	MUSCLE	LIVER
Inhalation	0	71	71	64	71	32
Air Submersion	0	0	0	0	0	0
Surface Exposure	18	2	2	30	2	4
Ingestion	82	26	27	6	27	64
Vegetables	4	9	10	1	10	22
Beef	75	9	9	3	9	22
Milk	3	8	8	2	8	20

Table 3-21. Contribution by radionuclide to various organ total doses, spent fuel/yard release case, WIPP site. Table gives percent of organ dose by nuclide. (Note: values less than 0.5% are shown as zero.)

NUCLIDE	GI TRACT	BONE/MARROW	THYROID	LUNGS	MUSCLE	LIVER
H-3	0	0	0	0	0	0
C-14	0	0	0	0	0	0
Fe-55	0	0	0	0	0	0
Co-60	1	0	0	2	0	0
Ni-63	0	0	0	0	0	0
Kr-85	0	0	0	0	0	0
Sr-90	9	28	28	5	28	64
Ru-106	70	0	0	1	0	0
Sb-125	0	0	0	1	0	0
I-129	0	0	0	0	0	0
Cs-134	7	1	1	13	1	3
Cs-137	9	3	3	19	3	7
Ce-144	0	0	0	0	0	0
Pm-147	0	0	0	0	0	0
Eu-154	2	0	0	3	0	0
Eu-155	0	0	0	0	0	0
Np-237	0	0	0	0	0	0
Pu-238	0	30	30	31	30	10
Pu-239	0	4	4	3	4	1
Pu-240	0	6	6	5	6	2
Pu-241	0	18	18	1	18	2
Pu-242	0	0	0	0	0	0
Am-241	0	6	6	5	6	5
Cm-242	0	0	0	4	0	0
Cm-244	0	5	5	8	5	4

3.5.4 Uncertainties

Every element of the consequence calculation is subject to uncertainty. A modest effort was made to list and to estimate the magnitudes of these uncertainties. Then, an overall uncertainty estimate for the consequence calculation was made by propagating the various uncertainty components.

Before proceeding, it is worthwhile to express some caveats. It has been mentioned several times that there were large uncertainties in some of the inputs to the consequence calculation. These uncertainties arose because of a lack of data on these input items, causing these input items to sometimes be estimated or derived by extrapolation. There is insufficient data to support a derivation of uncertainty magnitudes by the usual methods, i.e., statistics. As a result, the uncertainties derived herein are only estimates and should be considered as such. The various elements of the consequence calculation and their estimated uncertainty are as follows:

> Contents of Waste Containers The contents of spent fuel and HLW containers are well established. Contents of ILW and LLW containers may vary, but are of lesser interest. Uncertainties here are much less than for other items and are ignored.
>
> Release Fraction from Waste Container The release fractions are estimates largely unsupported by good data. Sandia's release estimates for particulates from spent fuel were baseline 0.07%, upper estimate 0.2%, lower estimate 0.02%. The differences between upper and baseline and baseline and lower estimates are about a factor of 3. This factor of 3 was assumed here to be representative of a one-sigma uncertainty for release fraction from spent fuel, although it is recognized that the uncertainty may, in fact, be much larger, especially since it applies to the release of respirable size particles and therefore also includes the uncertainties in particle size. A factor of ten uncertainty was assumed for other waste forms.
>
> Release Fraction From Facility There are a number of uncertainties in this calculation, including uncertainties in the initial particle size distribution, uncertainties in agglomeration (e.g., effects of humidity), and uncertainties in wall surface characteristics affecting deposition. The facility release fractions calculated herein were generally high, i.e., 40% to 90%. It is estimated that these fractions

are not likely to be significantly overestimated, but might be as much as a factor of two lower.

Air Transport Three uncertainty factors in air transport were considered, the effects of different weather, the effects of different deposition velocity, and overall model fidelity. Using a standard Gaussian plume model[28] mid-range chi over Q values were calculated for a matrix of seven stability classes and six discrete wind velocities. Statistical analysis of the resulting forty-two X/Q values gave a one-sigma standard deviation of a factor of two. This, however, does not contain the uncertainty effects due to precipitation. Similarly, variation of the deposition velocity resulted in a standard deviation of 33%. The uncertainties due to model fidelity are more difficult to assess. Comparison of calculated X/Q's with 321 experimentally measured values, shown in Figure 4.16 of Reference 29 indicated a one-sigma uncertainty of about a factor of two. This probably does not include uncertanties due to topography. Unpublished data by ORNL, in terms of predicted-to-observed X/Q ratios, indicates that complex terrain or meteorology can cause variations of more than a factor of a hundred. For purpose of further analyses herein, however, the one-sigma air transport uncertainty is assumed to be a factor of ten.

Dose Assessment The major source of population dose when effective countermeasures such as evacuation and food/drink interdiction are undertaken is inhalation of radioactive debris. The uncertainty factors considered here are dose factors, shielding effects and particle size. Dose factors from three sources[18,23,26] for five nuclides (Sr-90, Cs-134, Cs-137, Pu-238 and Pu-241) for several body organs were compared, and an average one-sigma variation was 36%. The effect of shielding, i.e., protection to population by buildings is expected to be small for desert and rural communities but might be larger, perhaps a factor of 3 on an average, for cities like NYC where buildings tend to be larger. This might also depend on the weather, since buildings would tend to be closed and fewer people outside in either hot or cold weather. The uncertainty due to particle size effects is estimated to be a factor of three, based on 50-year lung dose commitment factors for inhalation of plutonium calculated with the DACRIN[30] program (comparison of dose factors for 1 micron vs 10 micron particle sizes). The one-sigma dose assessment uncertainty was assumed to be a factor of three.

Health Effects Health risk effects have been studied by a number of committees, and fairly similar results have been derived despite the lack of good data and the need to extrapolate bomb survivor data (high dose to low dose), animal experiment data (animals to human) and medical data (radiation treatments of already ill patients) to the desired conditions. Also, different estimates exist depending on method of calculation, e.g., absolute risk model vs 30-year plateau. A simple statistical analysis of the health risk factors for all fatal cancers given in BEIR-I[20] and the withdrawn BEIR-1979[24] yielded a one-sigma uncertainty estimate of about a factor of 2.

One special effect which has been considered is the so-called "hot particle" effect. Uncertainties due to that effect weren't considered further here based on the discussion in Reference 31, in which the hot particle effect was discounted.

Overall Uncertainty The consequence calculation can be viewed as a product formula of the form

$$y = a \times b \times c \times d \times e$$

where y is the calculated consequences, and a, b, c, d, e, etc. are the above elements, i.e., contents of waste container, release fraction from waste container, release fraction from facility, air transport factor X/Q, dose assessment factor and health risk estimate factor.

The standard deviation in y may be propagated as follows (c.f., Reference 32, p 50),

$$S_y = \sqrt{S_a + S_b + S_c + \ldots}$$

where S_y, S_a, S_b, etc. are the fractional standard deviations, i.e., the ratio of the standard deviaion of a element to its estimated value.

Thus, the propagated error is simply the root-sum-square of the factors described in the above paragraphs. The resulting one-sigma error estimate is a factor of 11 for spent fuel and a factor of 15 for other waste forms.

4. PHYSICAL SECURITY REQUIREMENTS

4.1 GENERAL

In Chapter 3, it was shown that sabotage of a waste repository could result in severe consequences depending on the waste form and the repository location. Based on these data, it appears that some level of security to protect against sabotage is needed.

In this chapter, a set of physical security requirements for the waste repository is proposed. These security requirements are based on an assumed need to protect against on-site sabotage, theft for the purpose of off-site dispersal, and theft for the special nuclear material (SNM) content for the purpose of building a nuclear explosive. For the latter threat objective, i.e., theft of SNM, there are two potential sources of requirements, domestic and international.

As was shown in Chapter 3, the consequences of on-site sabotage and theft/sabotage are very strongly dependent on the waste form and, for on-site sabotage, the site location. A brief review of current and proposed NRC security requirements for protection of various nuclear facilities and different SNM categories indicates a wide variation in the level of security requirements. It therefore appears appropriate for waste repository security requirements to vary with the potential consequences.

The existence of several sets of NRC security requirements for different nuclear facilities and SNM categories also presents a practical approach to the derivation of security requirements for waste repositories. With available consequence estimates for severe accidents or sabotage incidents for the various facilities and SNM categories, it is possible to construct a consequence versus security-level relationship such as that shown in Figure 4-1, Step 1. Then, using that relationship and waste repository consequence data from Chapter 3, the corresponding level of security required for waste repositories can be derived as shown in Figure

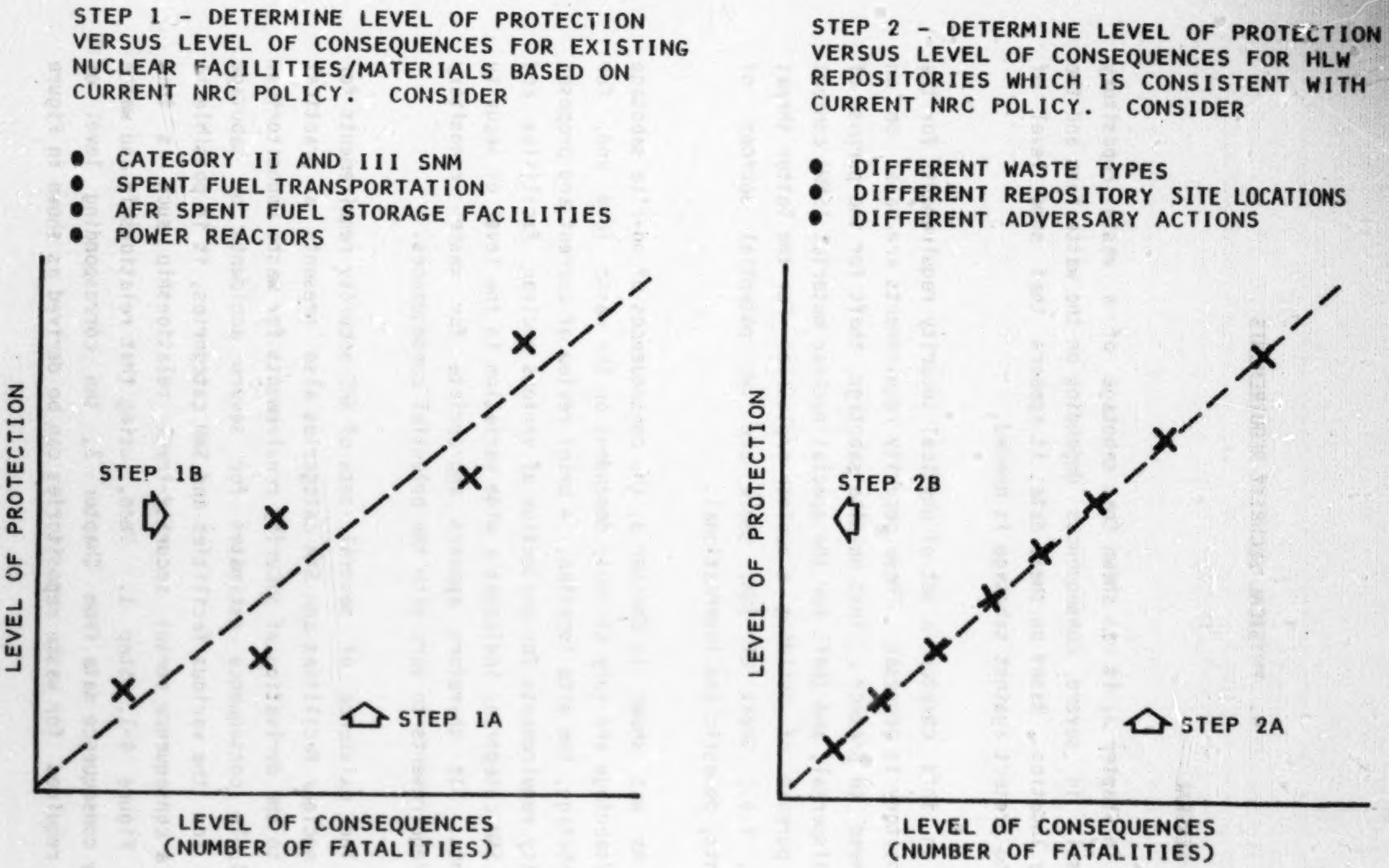
STEP 1 - DETERMINE LEVEL OF PROTECTION VERSUS LEVEL OF CONSEQUENCES FOR EXISTING NUCLEAR FACILITIES/MATERIALS BASED ON CURRENT NRC POLICY. CONSIDER
● CATEGORY II AND III SNM
● SPENT FUEL TRANSPORTATION
● AFR SPENT FUEL STORAGE FACILITIES
● POWER REACTORS
LEVEL OF PROTECTION
STEP 1B
STEP 1A
LEVEL OF CONSEQUENCES (NUMBER OF FATALITIES)
STEP 2 - DETERMINE LEVEL OF PROTECTION VERSUS LEVEL OF CONSEQUENCES FOR HLW REPOSITORIES WHICH IS CONSISTENT WITH CURRENT NRC POLICY. CONSIDER
● DIFFERENT WASTE TYPES
● DIFFERENT REPOSITORY SITE LOCATIONS
● DIFFERENT ADVERSARY ACTIONS
LEVEL OF PROTECTION
STEP 2B
STEP 2A
LEVEL OF CONSEQUENCES (NUMBER OF FATALITIES)

Figure 4-1. Approach for Determining Safeguards Requirements for HLW Repositories.

4-1, Step 2. In practice, this pragmatic approach yields a fairly detailed set of security requirements, although modifications to suit the specific nature of the facility are sometimes needed.

This approach is followed in the following sections. Section 4.2 describes current and proposed NRC security rules for other facilities and for SNM; Section 4.3 compares consequence levels; and Section 4.4 describes the resulting security level recommendations for protection against on-site and off-site sabotage. Section 4.5 then adds recommended domestic security requirements to protect against theft of SNM.

4.2 PHYSICAL SECURITY RULES FOR OTHER FACILITIES

Current and proposed physical security rules for nuclear reactors and away-from-reactor (AFR) spent-fuel storage facilities, spent-fuel transport, and Categories II and III SNM were considered in deriving physical security requirements for waste repositories. The security requirements for reactors and for AFR storage are most pertinent because these requirements are for fixed facilities, and are based, at least in part, on the need to protect against on-site sabotage. Part of the protective measures for Categories II and III SNM apply to fixed facilities, and part to the transportation of SNM. Only the requirements pertinent to fixed facilities were considered here. Also, the security requirements for Category II and III SNM were based on protection against theft rather than sabotage. However, the NRC authors of the Category II and III SNM security requirements expressed no objection to the correlation of those requirements with the consequences of Category II and III dispersal.

Last, and least applicable to the definition of waste repository security requirements, were the security requirements for spent-fuel transport. However, the spent-fuel transport regulations did provide some useful additional data on protection philosophy and measures and were therefore considered.

Table 4-1, which appears in six parts on seven pages, summarizes the physical security requirements for nuclear reactors, AFR fuel storage, Category II SNM and Category III SNM as specified by 10CFR73,[33,34] and several supporting Regulatory Guides, especially References 35 and 36, and NUREG-0575.[37] This table covers the security organization, physical barriers, access controls, alarm systems, communication and response, and miscellaneous requirements. It should be pointed out that the entries in Table 4-1 are summaries and that minor details are sometimes not included. However, the table gives a fairly comprehensive picture of the NRC physical security rules for the facilities and materials covered.

There is a very noticeable variation in the level of physical security requirements for the different facilities which appear in Table 4-1. The philosophy for protection against sabotage at reactors and AFR storage sites is clearly one of prevention, with armed guards and use of deadly force (as needed) specified. Protection of Category II and III SNM is largely concerned with theft detection, rather than prevention, with emphasis on alarms and notification of local law enforcement agencies (LLEA) for recovery. Thus, unarmed watchmen rather than armed guards, are specified for Category II protection. A watchman is not required for protection of Category III SNM if someone else is available to respond to alarms.

Table 4-2, which is based on 10CFR73.37 and on NUREG 0561,[38] summarizes the requirements for spent-fuel transportation. The requirements are given in two parts: 1) A set of requirements for spent-fuel transport in rural areas, and 2) additional requirements for transport through urban areas.

The primary objective of the spent-fuel transport rules is to prevent sabotage in or near highly-populated areas. Thus, the requirements for rural transport contain measures to respond to hijack attempts, while the added requirements for urban transport include armed guards to prevent or deter acts of sabotage.

Table 4-1a. Part 73, Physical Security Requirements for Existing Facilities/Materials -- Security Organization

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Security Organization	yes - capability to meet stated threat (73.55a)	yes (73.50a)	yes (73.47d8)	not required
Security Plan	yes (73.55b)	yes (73.50a3)	yes (73.47c1)	yes (73.47c1)
Security Supervisor	24 hrs/day authority to direct activities (73.55b)	24 hrs/day (73.50a2)	not required	not required
Security Force -- Guards and Watchmen	5 - 10 guards armed (73.55b, 73.55h3) available for immediate response	"Guards" armed (73.50a)	≥1 watchman per shift (73.47d8)	not needed - requires only that watchman or offsite force respond to alarms (73.47f3)
Security Force	T & Q per Appendix B, requalified annually (73.55b)	T & Q required per Appendix B, requalified annually (73.50a4)	not required	not required
Security Force Selection Criteria	selection per Appendix B (73.55b)	selection per Appendix B (73.50a4)	screening only (73.47d4)	not required

Table 4-1b. Part 73, Physical Security Requirements for Existing Facilities/Materials -- Barriers

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Barriers	2 - VA within PA VA barriers separated from PA barrier (73.55c)	2 - VA within PA VA barriers separated from PA barrier (73.50b)	1 - CAA (73.47d)	1 - CAA (73.47f1)
Gatehouse Protection	bullet resisting structure at PA (73.55d)	not required	not required	not required
Isolation Zone	adjacent to PA barrier (73.55c)	around PA barrier (73.50b4)	not required	not required
Illumination	isolation zone illuminated $\geq$0.2 foot-candles (73.55c)	isolation zone illuminated $\geq$0.2 foot-candles (73.50b5)	CAA illuminated (73.47d1)	not required
Protected Area Monitoring	PA peri. continuous. monitored, interior periodically checked (patrol) (73.55c4)	PA perimeter continuously monitored (73.50b4)	CAA monitored with alarms or procedures (73.47d2)	CAA monitored with alarms or procedures (73.47f2)
Employee Parking	outside PA barrier (73.55c3)	outside PA barrier (73.50c6)	no requirements	no requirements

Table 4-1c. Part 73, Physical Security Requirements for Existing Facilities/Materials -- Access Control (1 of 2)

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Protected Area Control	numbered picture badge for PA, displayed while in PA, coded badges for VA (73.55d5,d7)	picture badges (73.50c3)	badging system required (73.47d5)	no requirements
Positive Access Control (Job duty requires access)	people and vehicles in VA, limited access (73.55d7)	VA access controlled and limited (73.50c4)	limited access to CAA (73.47d6,d7)	no requirements
Search - Personnel	all persons entering PA (73.55d1) except regular employees (73.55 intro) by equipmnt	all persons entering PA (73.50c1) by equipment or physical search	no requirements	no requirements
Search - Packages	all handheld packages (73.55d2), delivered packages check for ID and searched (73.55d2)	random search of delivered packages All handheld packages searched (73.50c2,c1)	random for packages leaving CAA (73.47d10)	no requirements
Search - Vehicles	all except emergency (73.55d4)	not required but drivers must be escorted	random for vehicles leaving CAA (73.47d10)	no requirements
Delivery Vehicles	escorted to special receiving area not in VA (73.55d4)	escorted in PA (73.50c1)	no requirements	no requirements
Visitors	registered and escorted (73.55d6)	registered and escorted (73.50c5)	visitors under escort (43.47d7)	no requirements

Table 4-1c. Part 73, Physical Security Requirements for Existing Facilities/Materials -- Access Control (2 of 2)

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Keys, locks, combinations	to PA and VA controlled (73.55d9)	controlled (73.50c7)	not specified	not specified
Lock changes	when compromise suspected or employee terminates (73.55d9)	when compromise suspected or employee terminates (73.50c7)	not specified	not specified
Unoccupied VA or CAA	VA locked and alarmed (73.55d7)	VA locked and alarmed (73.50c4)	CAA locked and alarmed (73.47d3,d5)	CAA alarmed (73.47f2)

Table 4-1d. Part 73. Physical Security Requirements for Existing Facilities/Materials -- Alarm Systems

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Alarms to be tamper indicating	yes (73.55e)	yes (73.50 d1)	no requirement	no requirement
Alarm Stations	2 - CAS and SAS (73.55e1)	2 - CAS and SAS (73.50d1)	none required	none required
Central Alarm Station (CAS)	CAS in PA, CAS bullet resisting, CAS interior not visible from outside PA (73.55e)	CAS in PA (73.50d1)	no requirement	no requirement
Alarm Testing and Maintenance	maintained, tested at least weekly (73.55g)	tested at least weekly (73.50f2)	no requirement	no requirement
Emergency Exit Alarms	yes PA and VA (73.55c)	yes PA and VA (73.50d2)	none required	none required
Unoccupied VA or CAA	VA locked and alarmed (73.55d7)	VA locked and alarmed (73.50c4)	CAA locked and alarmed (73.47d3,d5)	CAA alarmed (73.47f2)
PA Perimeter Alarms	no specific requirement in 10CFR73. Monitoring can be accomplished using perimeter alarms and periodic patrol	no specific requirement in 10CFR73. Monitoring can be accomplished using perimeter alarms	no requirement specified in 10CFR73	no requirement specified in 10CFR73

Table 4-1e. Part 73, Physical Security Requirements for Existing Facilities/Materials -- Communication and Response

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Internal Communications	Each guard, watchman, response person in communication with CAS (73.55f1)	Guard, watchman continuous to CAS (73.50e1)	None required	None required
External Communications	Telephone and radio communication to LLEA from CAS & SAS (73.55f2,f3)	Telephone and radio to CAS to LLEA (73.50e2, e3)	Communication capability to response force (73.47d9)	Telephone
Communications, Emergency Power	Required (73.55f4)	Required (73.50e4)	None required	None required
Communication System Testing and Maintenance	Internal testing 1/shift, external 1/day (73.55g3)	Tested 1/shift (73.50f3)	No requirements	No requirements
Contingency Plan	Required (73.55h1)	Required (73.50g1)	Response procedures for theft or threat of theft (73.47d11)	Response procedures for theft or threat of theft (73.47f4)
LLEA Liasion	Established and documented (73.55h2)	Established and documented (73.50g2)	Not required	Not required
Use of Deadly Force	Required if needed (73.55h4)	Required if needed (73.50g3)	No requirement	No requirement
Remote Observation of PA Barrier and Isolation Zone	Required, pref by CCTV (73.55h5)	No requirement	No requirement	No requirement

Table 4-1f. Part 73, Physical Security Requirements for Existing Facilities/Materials -- Miscellaneous

FIXED SITE SECURITY MEASURE	REACTOR (SABOTAGE)	AFR STORAGE (SABOTAGE)	CAT II SNM (THEFT)	CAT III SNM (THEFT)
Reactor Control Room Protection	Walls, floor, ceiling bullet resistant (73.55c6)	N/A	N/A	N/A
Licensed Vehicle Usage	Used only by authorized persons (73.55d4)	No requirement	No requirement	No requirement
SNM Storage	N/A	N/A	Only in CAA (73.47d2)	Only in CAA (73.47f1)
Reports	Of lost SNM or theft or attempted sabotage reported to NRC (73.71)	Attempts of sabotage or of lost SNM or theft reported to NRC (73.71)	Report lost SNM to NRC (73.71)	Report lost SNM to NRC
Records	Authorized individuals, persons with access to VA, visitors and vendors Entry/exit to unoccupied VA; security tours and inspections; alarms, SNM shipments (73.70)	Authorized individuals, persons with access to VA, visitors and vendors, entry/exit to unoccupied VA, security tours and inspections, alarms, SNM shipments (73.70)	No requirement	No requirement

Table 4-2. Security Protection for Spent-Fuel Transportation Specified by Recent Interim NRC Rule.

REQUIREMENTS

- Notify NRC before Each Shipment
- Advance Approval of Route by NRC
- Trained Escorts
- Avoid Intermediate Stops
- Surveillance During Stops
- Establish Communication Center - Calls made each 2 hours
- Contingency Procedures
- Immobilization Features (Truck)

ADDITIONAL MEASURES FOR HEAVILY-POPULATED AREAS

- Armed Escort Force (1 police vehicle or 2 private vehicles)
- Avoid Stops

4.3 CONSEQUENCE LEVELS FOR FACILITIES OF INTEREST

The purpose of this section is to present estimated representative consequence levels for sabotage of the various facilities and materials of interest, including nuclear reactors, AFR storage sites, Categories II and III SNM and spent-fuel transportation and to summarize the representative consequences for sabotage of the waste repository. Those consequences can then be used, along with the safeguards data from Section 4.2, to derive safeguards requirements for the HLW repository.

Table 4-3 summarizes the representative consequences for the facilities and SNM categories listed above with the exception of the waste repository. The consequences listed are usually for very severe, perhaps worst case, events. The results in Table 4-3 were obtained from the indicated references. Although the references often gave a range of results, they did not give uncertainties. Since the different results were for different conditions (weather, population distribution or release event) and did not include the effects of many other computational uncertainties, it is not believed that the range of results were an indication of uncertainty. It is expected that these results have a large range of uncertainty.

The estimated consequences of about 50,000 latent plus acute fatalities for a nuclear reactor correspond to the worst-case estimates given in WASH-1400[39] for a class 1 accident, the worst accident analyzed. Although the consequences were calculated for a reactor accident, it is assumed here that they also represent the consequences of a severe sabotage event since the accident occurrences might be sabotage-initiated. The estimate of 45,000 latent fatalities was derived from data in Figures VI 13-33 of Reference 39, which indicates about 1500 late time cancer fatalities per year (for 30 years, as indicated by text in Reference 39, page 13-49), plus about 4000 early (first year) fatalities per Figure VI 13-30. Note that this represents a worst-case sabotage event with the highly unlikely situation in which all factors affecting consequences are at their worst conditions. It would require a successful sabotage that causes core melt, coupled with failure or sabotage of systems which would mitigate

Table 4-3. Potential Health Effect Consequences Associated with Adversary Actions Involving Different Nuclear Facilities/Materials.

NOTE: These results are generally worst-case consequences and include a wide range of uncertainty.

NUCLEAR FACILITY/MATERIAL	ADVERSARY ACTION	POTENTIAL LATENT HEALTH EFFECT CONSEQUENCES (NUMBER OF FATALITIES)	REFERENCE
CATEGORY III SNM	THEFT AND URBAN DISPERSAL	15 150	SAND77-1927 (40) NUREG/CR-0996 (7)
CATEGORY II SNM	THEFT AND URBAN DISPERSAL	200 1400	SAND77-1927 (40) NUREG/CR-0996 (7)
SPENT FUEL TRANSPORTATION	RURAL DISPERSAL	2	NUREG-0170 (41)
SPENT FUEL TRANSPORTATION	URBAN DISPERSAL	500 105	SAND77-1927 (40) NUREG/CR-0996 (7)
AFR SPENT FUEL STORAGE FACILITY	SABOTAGE	75	NUREG-0575 (37)
POWER REACTOR	SABOTAGE	45,000 (4,000 acute)	WASH-1400 (39)

the release, plus unfavorable weather conditions and exposure to a high population density.

The consequence estimate of 500 fatalities for urban dispersal in spent-fuel transport cask sabotage is based on truck cask results from Reference 39 (SAND 77-1927). Revised results by Sandia[7] have reduced the consequence estimates, but the interim NRC rules for spent-fuel transport security as used herein were based in part on the SAND 77-1927 results; therefore, the SAND 77-1927 consequences are included here. Work on spent-fuel transportation consequences analysis and rulemaking is still in progress.

The consequence estimates of 200 fatalities for dispersal of Category II SNM and 15 fatalities for dispersal of Category III SNM are based on SAND 77-1927 estimates for urban dispersal of 1000 grams of plutonium and 100 grams of plutonium, respectively, in the form of a plutonium dioxide powder of which 20% is of respirable size.

The estimate of 75 fatalities for sabotage of an AFR spent-fuel storage facility was based on results for the worst case sabotage event described in Reference 37 (NUREG-0574). This sabotage event involved an explosive attack on twenty spent-fuel elements in the air space of a cask unloading cell with the HEPA filters ruptured or removed and the ventilation flow maintained. This event was chosen as "representative" here despite the fact that no current AFR facility unloads fuel element shipping casks in air and despite the much lower consequences for attack on underwater fuel (typically 3 x 10^{-5} fatalities estimated in Reference 36).

The estimates of 2 fatalities for sabotage of a spent-fuel shipping cask in a rural area was derived from data in Reference 40, which indicated 220 late cancer fatalities (LCFs) for such an event in an area populated by 2000 people per square mile. A typical rural population is 16 people per square mile. The expected number of rural LCFs (i.e., about 2) is simply 220 times the population density ratio (16/2000).

Table 4-4 gives a summary of the potential consequences associated with various waste forms in the waste repository. The data in this table was derived from the 24-hour exposure dose with food interdiction* results given in Chapter 3 (specifically Table 3-10) by selecting the maximum dose target locations and rounding the values. It may be noted that the number of fatalities for the generic rural site is about a factor of ten larger than the number of fatalities for the generic desert site, and the consequences for a theft/sabotage event with release in New York City are about a factor of 1000 greater than the consequences for on-site sabotage at the desert site. These factors correspond roughly to the ratio of population density in these areas.

4.4 PROPOSED SECURITY REQUIREMENTS FOR PROTECTION AGAINST SABOTAGE

In this section, the data of the previous sections (4.2 and 4.3) are combined with the approach discussed in Section 4.1 to derive a proposed set of physical security requirements to protect a high-level waste repository against radiological sabotage. This discussion is divided into two parts, protection against on-site sabotage and protection against theft for the purpose of off-site dispersal.

4.4.1 Protection Against On-Site Sabotage

Table 4-5 defines four levels of physical security protection, very high, high, moderate and low, in terms of several key security measures for protection of fixed sites from on-site sabotage. Figure 4-2 then shows the relationship between security level and consequences for several nuclear facilities, materials and operations, using these definitions and the consequence data from Section 4.3. As is apparent in Figure 4-2, there is a definite correlation between level of protection and level of consequences.

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*Larger health effects values were calculated for 365-day exposure without food interdiction (Table 3-12). It was believed, based on those results, that evacuation and food interdiction would take place after radiological sabotage, and that it would be appropriate to base security measures on the reduced consequences.

Table 4-4. Potential Health Effect Consequences Associated with Sabotage (On-Site Dispersal) Involving Different Waste Types and Different Repository Site Locations.

	POTENTIAL HEALTH EFFECT CONSEQUENCES (NUMBER OF FATALITIES)		
	REMOTE REPOSITORY SITE[(a)]	RURAL REPOSITORY SITE[(b)]	ANY REPOSITORY SITE
WASTE TYPE	SABOTAGE (Remote Dispersal)	SABOTAGE (Rural Dispersal)	THEFT AND URBAN[(c)] DISPERSAL
SPENT FUEL	1	10	300
VITRIFIED HLW W/O Pu	3	50	300
VITRIFIED HLW W Pu	100	1,000	7,000
CALCINED HLW W/O Pu	30	500	4,000
CALCINED HLW W Pu	1,000	10,000	100,000

(a) REPRESENTED BY WIPP SITE (150,000 POPULATION WITHIN 80 km)

(b) REPRESENTED BY GEIS SITE (2,000,000 POPULATION WITHIN 80 km)

(c) REPRESENTED BY NEW YORK CITY

Table 4-5. Definitions -- Levels of Physical Security Protection for Fixed Sites

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
SECURITY				
• ORGANIZATION	Required	Required	Required	Not required
• SUPERVISOR	24 hours/day	8 hours/day	Part time	Not required
• GUARDS/SHIFT	5-10 guards	3-6 guards	1-3 watchmen	0-1 watchmen
BARRIERS				
• NUMBER	2 (PA&VA)	2 (PA&VA)	1 (CAA)	1 (CAA)
• ISOLATION ZONE	Required	Required	Not required	Not required
• PA/CAA MONITOR	Required	Required	Required	Required
ACCESS CONTROL				
• POS CONTROL	In PA	In VA	Not required	Not required
• BADGES	Required	Required	Required	Not required
• SEARCH				
- PERSONNEL	All	Random	Random	Not required
- PACKAGES	All	Random	Random	Not required
ALARM SYSTEMS				
• ALARM STNS	2	1	None	None
• UNOCCUPIED VA/CAA	Required	Required	Required	Required
COMMUNICATIONS				
• EXTERNAL	Radio/Telephone	Radio/Telephone	Telephone	Telephone
RESPONSE				
• LLEA LIAISON	Documented	Documented	Not required	Not required
• DEADLY FORCE	If needed	If needed	No requirement	No requirement

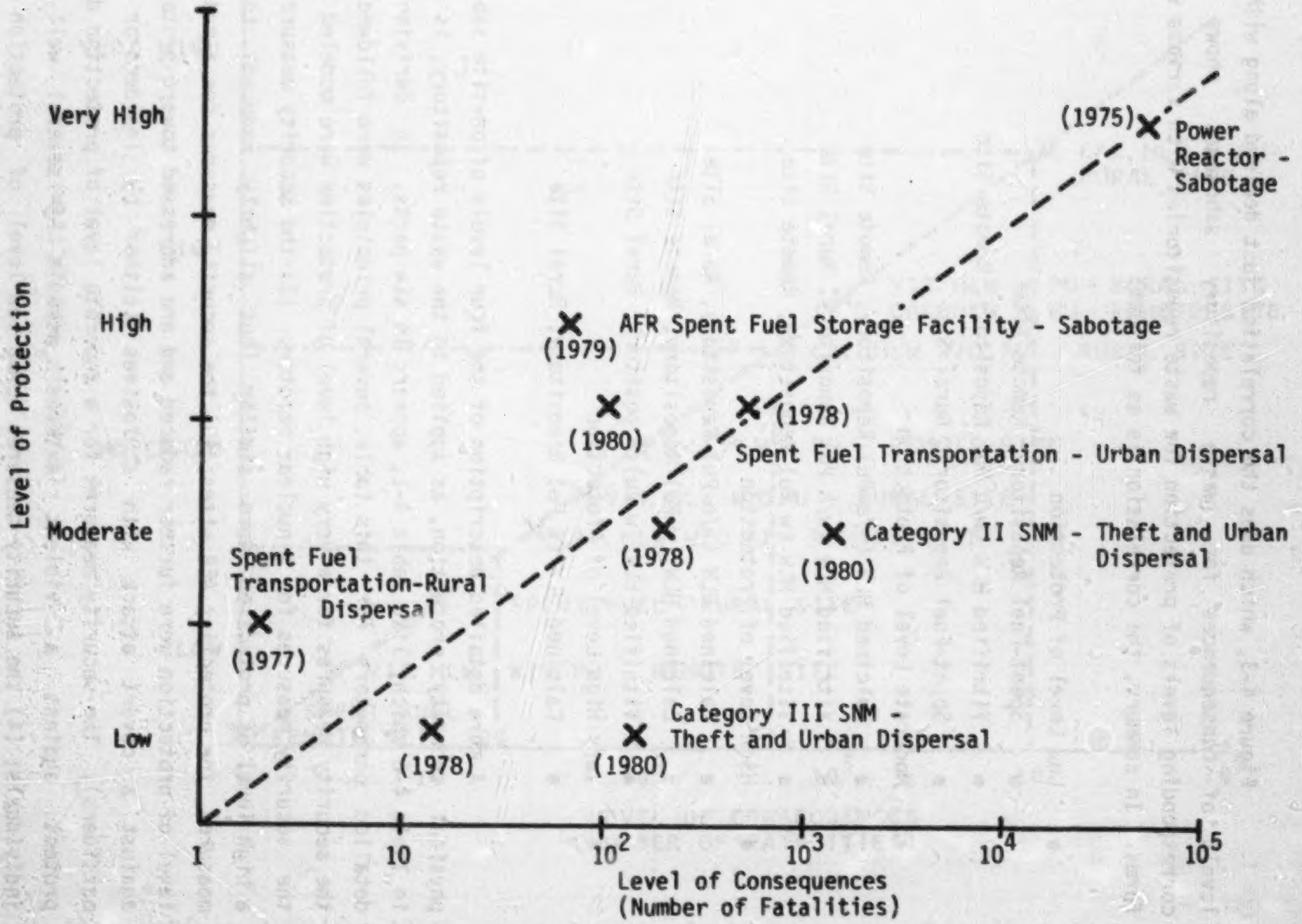

Figure 4-2. Level of protection vs level of consequences for existing nuclear facilities/materials

A smoothed correlation, represented by the dashed diagonal line on Figure 4-2, was assumed for subsequent analysis.

Figure 4-3, which uses the correlation just derived along with the levels of consequences for waste repository sabotage, shows the corresponding levels of protection for waste repositories with various waste forms. In summary, the correlation is as follows:

- Low Level of Protection
    - Spent-Fuel Repository, Remote Site
    - Vitrified HLW (w/o Pu) Repository, Remote Site
    - Spent-Fuel Repository, Rural Site
- Moderate Level of Protection
    - Calcined HLW (w/o Pu) Repository, Remote Site
    - Vitrified HLW (w/o Pu) Repository, Rural Site
    - Vitrified HLW (w Pu) Repository, Remote Site
- High Level of Protection
    - Calcined HLW (w/o Pu) Repository, Rural Site
    - Calcined HLW (w Pu) Repository, Remote Site
    - Vitrified HLW (w Pu) Repository, Rural Site
- Very High Level of Protection
    - Calcined HLW (w Pu) Repository, Rural Site

A more detailed description of the four levels of on-site sabotage physical security protection, as applied to the waste repository, is given in Table 4-6 which, like Table 4-1, appears in six parts. In deriving the detailed parameters for this table, several principles were followed: (1) the security measures for a very high level of protection were modeled after the security measures for a nuclear reactor, (2) the security measures for a high level of protection were similar (but slightly reduced) to the measures for protecting AFR sites; (3) the security measures for a moderate level of protection were further reduced and are addressed toward protecting against a covert attack with explosives (either by insiders or a few outsiders). The security measures for a moderate level of protection do not protect against a violent external assault by several well-armed individuals; (4) the security measures for a low level of protection were

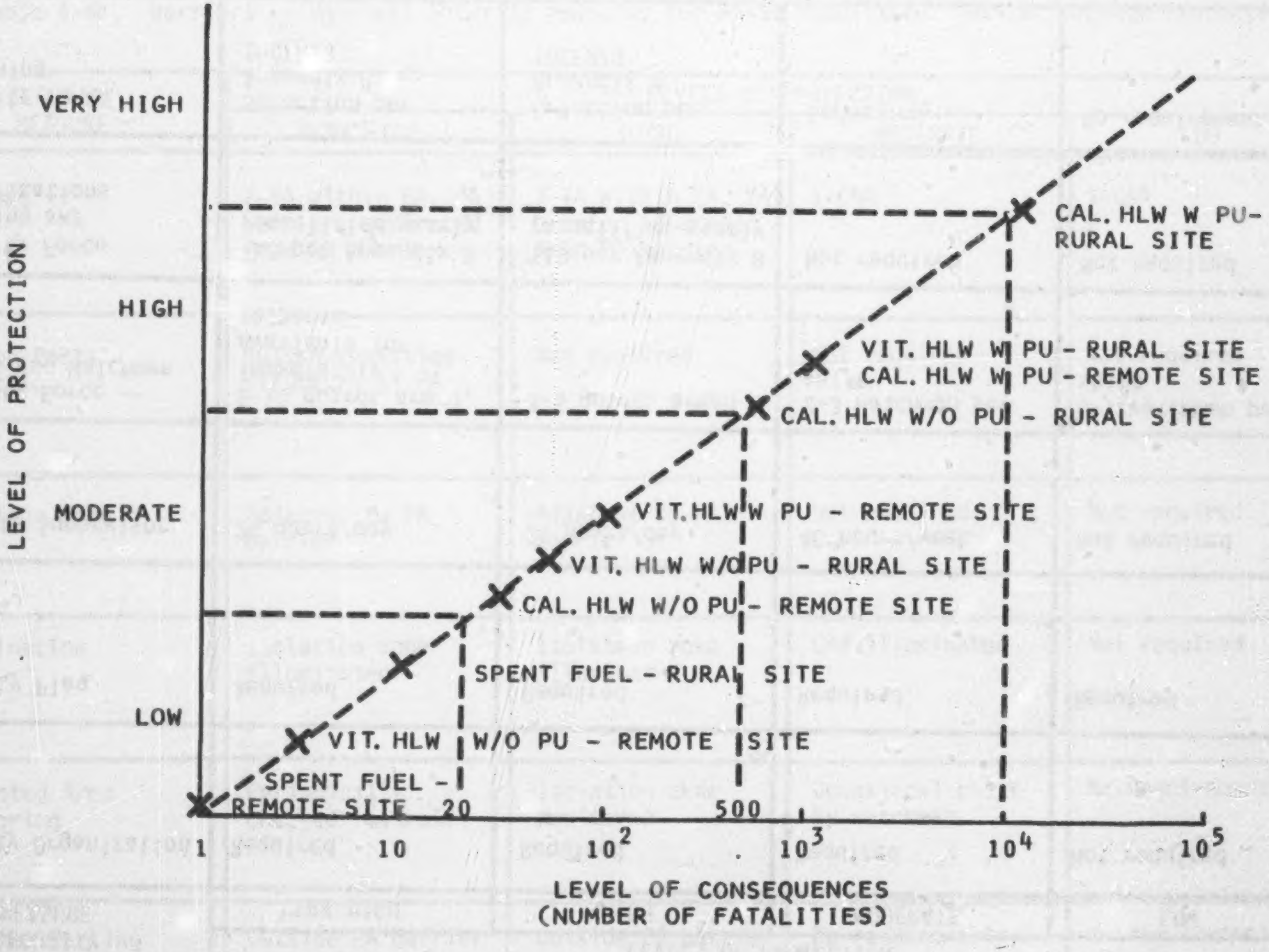

Figure 4-3. Level of protection vs level of consequences for sabotage (dispersal) at HLW repository site

Table 4-6a. Security Organization -- Physical Security Measures for Waste Repository, Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Security Organization	Required	Required	Required	Not required
Security Plan	Required	Required	Required	Required
Security Supervisor	24 hours/day	24 hours/day	40 hours/week	Not required
Security Force -- Guards and Watchmen	5-10 guards armed, immediately available for response	3-5 guards armed	2-3 watchmen per shift	0-1 watchmen per shift
Security Force Training and Qualifications	T&Q per Appendix B requalified yearly	T&Q per Appendix B requalified yearly	Not required	Not required
Security Force Screening	Selection per Appendix B 10CFR73	Selection per Appendix B 10CFR73	Screening	No requirement

Table 4-6b. Barriers -- Physical Security Measures for Waste Repository Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Barriers	2-VA within PA, VA barriers separated from PA barrier	2-VA within PA, VA barrier separated from PA barrier	1-CAA	1-CAA
Barrier Portal Protection	Bullet-resisting structure at PA	Not required	Not required	Not required
Isolation Zone	Adjacent to PA barrier	Adjacent to PA barrier	Not required	Not required
Illumination	Isolation zone illuminated	Isolation zone illuminated	CAA illuminated	Not required
Protected Area Monitoring	Periodically checked (patrol)	Isolation zone monitored	Occasional check by watchman	No requirement
Employee Parking	Outside PA barrier	Outside PA barrier	No requirements	No requirements

Table 4-6c. Access Control -- Physical Security Measures for Waste Repository Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Positive Access Control	Limited access people and vehicles in VA	VA access controlled	CAA access control	No requirements
Badges	Numbered picture for PA displayed while in PA, coded badges for VA	Picture badge	Badging system required	No requirements
Search -- Personnel	All persons except regular employees entering PA	Random search of persons entering PA	Random search of persons entering CAA	Not required
Search -- Packages	All handheld and delivered packages	Random search of handheld and delivered packages	Random search of handheld and delivered packages	Not required
Search -- Vehicles	All except emergency	Random search of entering vehicles	Random search of entering vehicles	Not required
Delivery Vehicles	Escorted to special receiving area not in VA	Escorted in PA	No requirements	No requirements

Table 4-6c (continued). Access Control -- Physical Security Measures for Waste Repository Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Visitors	Registered and escorted	Registered and escorted	Escorted	No requirements
Employee Screening	No requirements	No requirements	No requirements	No requirements
Keys, Locks, and Combinations	To PA and VA controlled	To PA and VA controlled	CAA locks controlled	CAA locks controlled
Lock Changes	When compromise suspected or employee terminates	When compromise suspected or employee terminates	No requirements	No requirements
Unoccupied VA or CAA	Locked and alarmed	Locked and alarmed	Locked and alarmed	Locked and alarmed

Table 4-6d. Alarm Systems -- Physical Security Measures for Waste Repository Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Alarms Indicate Tampering	Yes	Yes	No requirement	No requirement
Alarm Stations	2-CAS and other	1	None required	None required
Central Alarm Station (CAS)	CAS in PA, CAS bullet resisting CAS interior not visible from outside PA	No requirement	No requirement	No requirement
Alarm Testing and Maintenance	Maintained, tested at least weekly	Tested at least weekly	No requirements	No requirements
Emergency Exit Alarms	Yes, PA and VA	Yes, PA and VA	Yes CAA	Not required
Unoccupied VA or CAA	VA locked and alarmed	Locked and alarmed	Locked and alarmed	Locked and alarmed
PA Perimeter Alarms	No requirement	No requirement	No requirement	No requirement

Table 4-6e. Communication and Response -- Physical Security Measures for Waste Repository Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Internal Communications	Each guard, watchman, response person in communication with CAS	Guard, watchman in communication with alarm station	Internal communication between watchmen	Not required
External Communications	Telephone and radio communication to LLEA from CAS	Telephone and radio communication to LLEA	Telephone	Telephone
Communications' Emergency Power	Required	Required	Not required	Not required
Communications System Testing and Maintenance	Tested each shift	Tested each shift	No requirements	No requirements
Contingency Plan	Required	Required	Required	Required
LLEA Liaison	Documented	Documented	Not required	Not required
Use of Deadly Force	Required if needed	Required if needed	Not required	Not required
Remote Observation of PA Barrier and Isolation Zone	Required, preferably by CCTV	No requirement	No requirement	No requirement

Table 4-6f. Miscellaneous -- Physical Security Measures for Waste Repository Onsite Sabotage Protection

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Reports	Sabotage or attempted sabotage reported to NRC	Sabotage or attempted sabotage reported to NRC	Sabotage or attempted sabotage reported to NRC	Sabotage or attempted sabotage reported to NRC
Records	Authorized individuals, persons with access to VA, visitors and vendors, entry/exit to unoccupied VA, security tours and inspections, alarms	Authorized individuals, persons with access to VA, visitors & vendors, security tours and inspections, alarms	Persons with access to CAA, entry/exit to unoccupied VA, security inspections, alarms	No requirements

still further reduced and are similar to the level of protection afforded Category III SNM. (This level of protection will not protect against a determined external assault, but would provide some protection against covert acts.); (5) a level of consistency was maintained. For example, the number of guards and watchmen must be consistent with the functions to be performed; i.e., gates to be monitored, searches performed, patrols, etc.

Although fairly large uncertainties in the calculated consequence results were estimated in Chapter 3, it is expected that the levels of protection recommended above are valid. The uncertainty in the calculated consequences from spent-fuel sabotage was estimated to be a factor of 11 and the uncertainty in the calculated consequences for sabotage of other waste forms was estimated to be a factor of 15. Uncertainty values for the comparative events data (Table 4-3) were not available from the source literature, but it is expected that the same magnitude of uncertainty applies since the same general calculational approach and data were used in their derivation. However, since this approach to the derivation of levels of protection involved a comparison of calculated consequence results, the relative, not absolute, magnitude of the uncertainties are importaint. The relative uncertainties are not known, but are expected to be significantly less than the absolute uncertainty because of the same or similar calculation methods and data. This relative uncertainty is expected to be within the resolution of the level-of-protection structure derived and shown in Figure 4-3.

4.4.2 Protection Against Theft/Sabotage

Figure 4-4, which uses the level-of-protection vs consequences correlation of Figure 4-2 and the off-site dispersal consequences of Table 4-4, gives the levels of physical protection required for equivalent protection against theft for the purpose of dispersal at an off-site location. The levels of protection for the various waste forms are as follows:

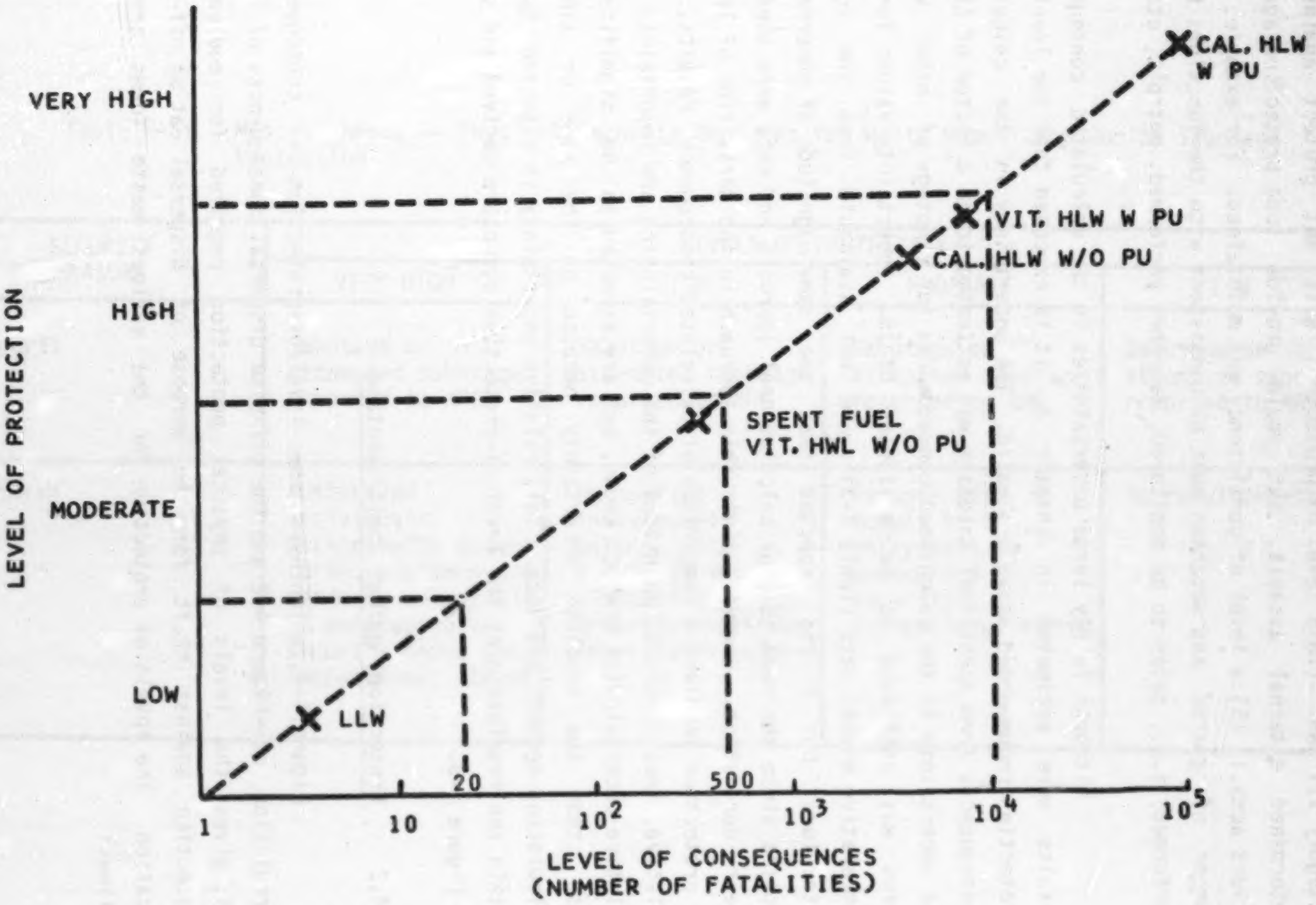

Figure 4-4. Level of protection vs level of consequences for theft and urban dispersal

- Low Level of Protection
    - LLW
- Moderate Level of Protection
    - Spent Fuel
    - Vitrified HLW w/o Pu
- High Level of Protection
    - Calcined HLW w/o Pu
    - Vitrified HLW with Pu
- Very High Level of Protection
    - Calcined HLW with Pu

Generally, these levels of protection are about one level above that needed for protection against on-site sabotage. But because theft/sabotage requires not only that an antagonist enter a facility, but that he must exit with a not-easily concealed cargo and transport it to some presumably distant target location, it is much easier to protect against theft/sabotage than on-site sabotage. Therefore, the increased levels of protection required for theft/sabotage protection need not add greatly to the cost or complexity of the overall security system. Protection against on-site sabotage requires preventive measures such as barriers and armed guards. But protection against theft/sabotage requires largely detection and communication measures since there will usually be time for law enforcement intercept and recovery of the stolen material.* This intercept and recovery action is facilitated, for the most dangerous waste forms (HLW and spent fuel) by the size, weight and obvious character of the shipping casks which even a saboteur would need to use.

Removal of waste, once emplaced in the repository, would be much more difficult than theft of material in the receiving yard because of the nature of the facility and the generally one-way flow of waste materials. Therefore, it is expected that waste material in the receiving area, especially material still loaded on the transport vehicle, would be most vulnerable to theft. For this reason, protective measures to detect the exit of waste material at the facility gate (PA, VA or CAA) appear adequate.

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*This assumes that the repository is not located near a likely off-site target. If the respository is located near a likely off-site target such as a city, air base, missile base, nuclear weapon storage site, etc., additional preventive measures would be warranted.

Table 4-7 describes additional the physical security measures recommended to protect against theft/sabotage acts. As discussed above, the security measures address primarily detection of exiting material at the exit gate. It matters little whether the exit control point is a PA, VA or CAA boundary or other door or gate, just so long as exiting vehicles are checked for waste contents. It is assumed that vehicles exiting at unorthodox locations (e.g., through or over the fence) will be detected.

The security measures at the gate involve primarily the inspection of departing vehicles. This means inspection of those vehicles which have the capacity to carry waste cargo, including spent fuel, HLW and ILW shipping casks. Inspection of the cask interior at the gate will not be practical, but casks can be inspected for seals indicating that they are empty, and cask surface dose rates can be measured as a backup to detect any high level content.

The security measures proposed here for protection against theft/sabotage do not include any requirements for keeping records of waste inventory. No requirements for records were believed necessary for this purpose; it is doubtful that recordkeeping would provide timely enough detection of material loss to prevent dispersal in areas within a few hundred miles of the repository.

4.5 PROPOSED SECURITY REQUIREMENTS FOR PROTECTION AGAINST SNM THEFT

A number of additional security measures are necessary to protect against (and to give assurance of protection against) the theft of waste material for its SNM content. While most of the measures just described for protection against sabotage also help to protect against SNM theft, those measures must be supplemented to satisfy both domestic and international protection requirements.

Table 4-7. Additional Physical Security Measures for Protection Against Theft/Urban Sabotage

SECURITY MEASURE	LEVELS OF PROTECTION			
	VERY HIGH	HIGH	MODERATE	LOW
Waste handling and storage	Within enclosed area	Within enclosed area	Within enclosed area	Within enclosed area
Watchman/guard at exit gate for waste vehicles	Guard 24 hours/day	24 hours/day	Required at time of vehicle exit (gate locked)	Not required (gate or door locked)
Inspect exit vehicles for waste cargo	Required, all vehicles	Required, all vehicles	Random check required	Not required
Waste vehicle exit portal	Bullet-resisting structure	No requirement	No requirement	No requirement
External communications	Radio and telephone to LLEA	Radio and telephone to LLEA	Telephone	Telephone
Communications' Emergency Power	Required	Required	Not Required	Not required
Place seals on empty shipping casks	Required	Required	Required	Not applicable
Reports	Report any attempted theft of waste material to NRC	Report any attempted theft of waste material to NRC	Report any attempted theft of waste material to NRC	Report any attempted theft of waste material to NRC

The emphasis here is, of course, related to the SNM content of the waste rather than to its potential for causing radiological consequences. The SNM content might be the amount inherent in the waste, or it might be a larger amount altered either accidently or intentionally (smuggling). Based on the data in Table 3-6, the typical plutonium contents of the various waste containers will be approximately the following:

Spent Fuel (PWR)	4,000 grams
HLW (w/o Pu)	150 grams
HLW (w Pu)	30,000 grams
Cladding Hulls	20 grams
ILW	5 grams
LLW (TRU)	8 grams

The largest quantities of plutonium are clearly in spent fuel and HLW for the uranium-only-recycle fuel cycle. But also important is the ease of handling the material. In this latter respect, the LLW, which can be contact handled, is favored. However, several hundred drums of LLW would be needed to obtain a formula quantity of Pu, even if 100% recovery of the Pu from the waste were achievable.

4.5.1 Domestic Requirements for Protection Against SNM Theft

There are two basic kinds of SNM protection requirements: one is the physical protection requirements as described in 10CFR73;[33] the other is the material control and accounting (MC&A) requirements as described in 10CFR70.[42] The MC&A requirements for protection against SNM theft are discussed in Chapter 6. It is expected, because of the bulk and high radiation levels associated with spent fuel, HLW, ILW and cladding hulls, that no physical protection measures in addition to those already discussed for protection against theft/sabotage will be needed to protect against theft of these waste forms for their SNM content. However, one additional measure to protect against the removal of small packages of smuggled high-purity SNM may be appropriate, depending on the safeguards provided at waste shipper facilities. This measure would be random searches of exiting personnel, vehicles and packages made with an SNM detector to provide deterrence against the removal of small packages of SNM that may have been smuggled between facilities along with valid waste. In this respect, the LLW facility, both above and below ground, should be emphasized because of the ease with which LLW drums can be handled and opened.

A few more words about the SNM smuggling threat and protection measures are appropriate. First, quantities of SNM might be smuggled between nuclear facilities, for example, between a fuel reprocessing plant and a waste repository, in order to evade SNM theft protection measures at the shipper facility. Smuggling of quantities of SNM, presumably in pellets, vials or other compact forms, might be accomplished by placing the SNM in a LLW drum or in a shipping vehicle exterior to the waste containers. Also, it is possible that SNM could be smuggled via a substitution strategy in which a dummy waste cannister contains SNM instead of the usual waste.

The primary protection against the smuggling activity should take place at shipper facilities, i.e., the MC&A at these facilities. Protective measures at the HLW repository serve primarily as a backup by providing further deterrence to this theft pathway. Because it is only a backup protective measure, random searches, rather than total searches, may be appropriate. If, however, MC&A at a shipper facility should reveal SNM losses, the frequency of searches can be increased.

4.5.2 International Requirements for Protection Against SNM Diversion

No additional physical security measures are believed necessary to satisfy international (IAEA) requirements. International material control and accounting (MC&A) requirements are discussed in Chapter 6.

4.6 ALTERNATIVE SECURITY MEASURES

The approach used here to derive physical security requirements for a high-level waste repository (i.e., the application of requirements for other facilities with similar consequence potential) resulted in sets of security requirements which are practical and time-proven. It is quite possible, however, that alternative security measures might be more cost effective.

Alternatives can be considered at any level. The four sets of requirements described in Section 4.4 for the four levels of protection may be viewed as alternatives. On a lower level, there are hardware alternatives (e.g., one type of detector versus another or hardware versus personnel tradeoffs); on a higher level, there are procedural alternatives, such as a simple statement that a facility must be protected against sabotage versus detailed requirements designed to give the desired protection.

At this highest level, the practice of NRC has clearly been to specify the methodology used to provide protection. No change in this procedure is recommended. Alternative formats for presentation of the requirements are possible, both inside and outside of the Code of Federal Regulations (CFR). The current procedure procedure of issuing NUREG and Regulatory Guide reports in support to CFR appears satisfactory.

On an intermediate level, some tradeoff between containment and protection may be possible. If, for example, the HEPA filters and their controls are protected to prevent their sabotage, the protecton of interior facilities might be relaxed. Typically, HEPA filters are expected to reduce the emission of pollutants by about 99.95%. This would reduce latent consequence effects to the off-site population by a factor of 2000. Based on the level of protection versus level of consequences relationship (Figure 4-3), only a low-level of protection against on-site sabotage would be needed for all interior (waste receiving building to emplacement area) parts of the facility. Furthermore, parking and railroad siding areas for not yet unloaded shipping casks could be enclosed, thus, reducing the entire facility (except the filters) to a low level of protection. Protection of these filters is quite feasible, and the associated security costs would be substantially reduced for a facility otherwise requiring either a high- or very high-level of protection. The security requirements for protection against theft/sabotage and SNM theft would, however, be unaffected. Also, protection of the filters would not protect the repository or repository workers from the effects of sabotage.

There is more discussion on physical security alternatives in Chapter 5.

[illegible] affected.

[illegible] requirements, described in Section [illegible] for the four levels of protection [illegible] be viewed as alternatives. [illegible] alternatives (e.g., [illegible] protection.

[illegible]

[illegible]

5. EXAMPLE REPOSITORY PHYSICAL SECURITY SYSTEM DESIGN

5.1 GENERAL

In this chapter, an example repository physical security system is designed to (1) provide a demonstration of the security system requirements proposed in Chapter 4, (2) demonstrate the feasibility of implementing these requirements and (3) provide a baseline system for estimating potential security system costs and societal impacts.

As noted earlier, there are a number of bases for physical security requirements including on-site sabotage, theft/off-site dispersal and SNM theft. Also, there is a need for industrial security, but industrial security is not considered here. As indicated in Chapter 4, there are several different levels of protection requirements, depending on waste type and repository location. Thus, a number of security system designs are required.

In this chapter, example physical security system designs are evolved as follows: first, the security system design for physical protection against on-site sabotage is developed (Section 5.2). Second, the additional features required for physical protection against theft/off-site dispersal are specified (Section 5.3). And third, the additional features for domestic SNM physical protection requirements are developed (Section 5.4). Cost estimates for the security system designs are also derived.

Before proceeding, however, the physical security features apparent from the plot plans of surface facilities for two different designs (PBQD and WIPP) are briefly compared with each other and with the security requirements discussed in Chapter 4. Also, a basis for estimating security component costs is presented.

Figures 5-1, 5-2, and 5-3 show, respectively, an artist's three-dimensional concept of the Parson's, Brinkerhof, Quade and Douglas (PBQD, Reference 1) design, the plan view showing the layout of surface facilities for that design, and the layout of surface facilities for the WIPP as described in References 4 and 6. These designs show several surface facilities which are pertinent to security system design and a number of facilities which are not of direct importance to the security system. Facilities of direct importance include the RH and CH waste receiving and handling facilities, waste receiving yards including railroad sidings and outside truck cask parking areas, the various mine access shaft head frames, and the building containing the HEPA filter. In both the WIPP and PBQD designs, all the above facilities are located inside an encircling PA barrier consisting of a double fence with isolation zone and gatehouses.

These designs also show a number of surface facilities which are of lesser importance to the physical security system. These include the administrative building, cafeteria, equipment storage building, water supply, sewage plant and lagoon, power plant, rad waste plant, electrical substation, clinic, laundry, etc. In both designs, most of these surface facilities are inside the PA boundary. Exceptions are the administration building, which forms part of the PA boundary for the WIPP facility and which is completely outside the PA boundary in the PBQD design, and the clinic, warehouse and maintenance facility, which are outside the PA boundary in the PBQD design.

Other features which are worth noting here are the employee parking lot, and the mined material storage area, which are outside the PA boundary in both designs, conveyors for mined material crossing the PA boundary (both designs) and a coal conveyor crossing the PA boundary (PBQD design only). The WIPP has a single entrance for all traffic (foot, truck, rail) while the PBQD design has one entrance for foot and truck traffic and a separate entrance for rail traffic.

Before proceeding with the security system designs and cost estimates, the basis for the cost estimates is discussed. Cost estimates for several security system components were obtained from Reference 43,

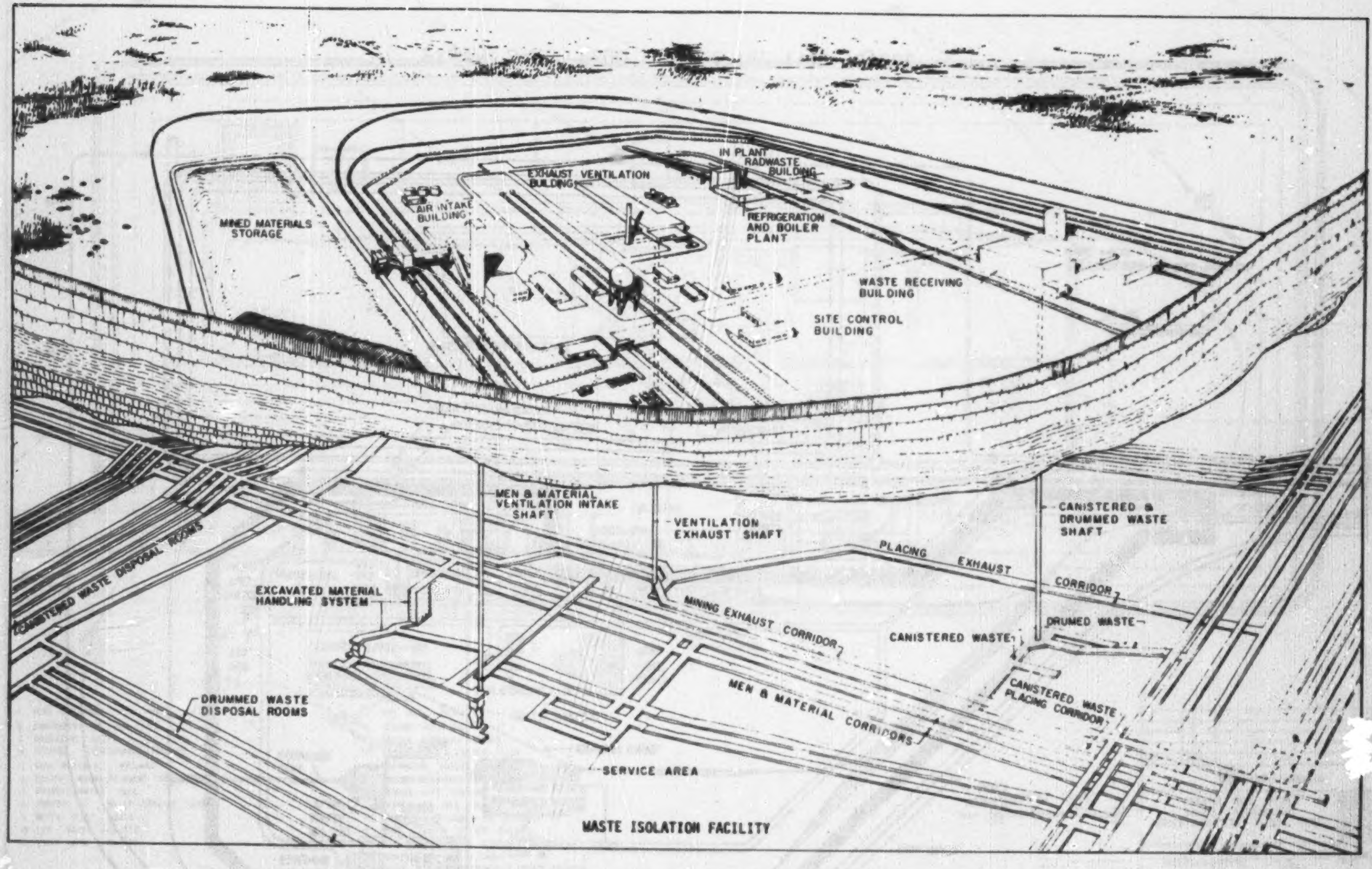

IN PLANT RADWASTE BUILDING
EXHAUST VENTILATION BUILDING
AIR INTAKE BUILDING
MINED MATERIALS STORAGE
REFRIGERATION AND BOILER PLANT
WASTE RECEIVING BUILDING
SITE CONTROL BUILDING
MEN & MATERIAL VENTILATION INTAKE SHAFT
VENTILATION EXHAUST SHAFT
CANISTERED & DRUMMED WASTE SHAFT
PLACING EXHAUST CORRIDOR
CANISTERED WASTE DISPOSAL ROOMS
EXCAVATED MATERIAL HANDLING SYSTEM
MINING EXHAUST CORRIDOR
CANISTERED WASTE
DRUMED WASTE
CANISTERED WASTE PLACING CORRIDOR
DRUMMED WASTE DISPOSAL ROOMS
MEN & MATERIAL CORRIDORS
SERVICE AREA
WASTE ISOLATION FACILITY

Figure 5-1. Artist's concept of high level waste repository.

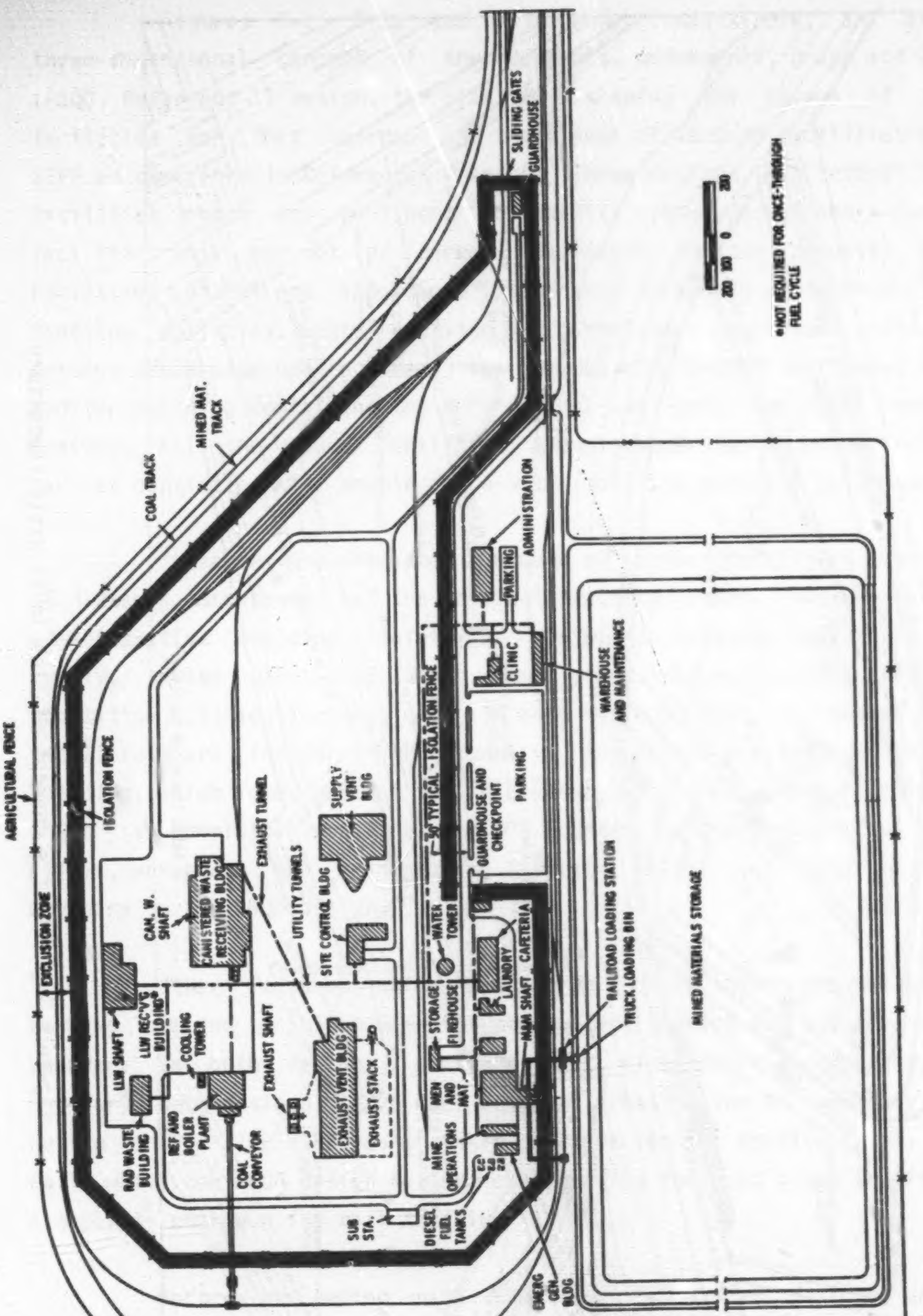


Figure 5-2. PBQD surface facility layout

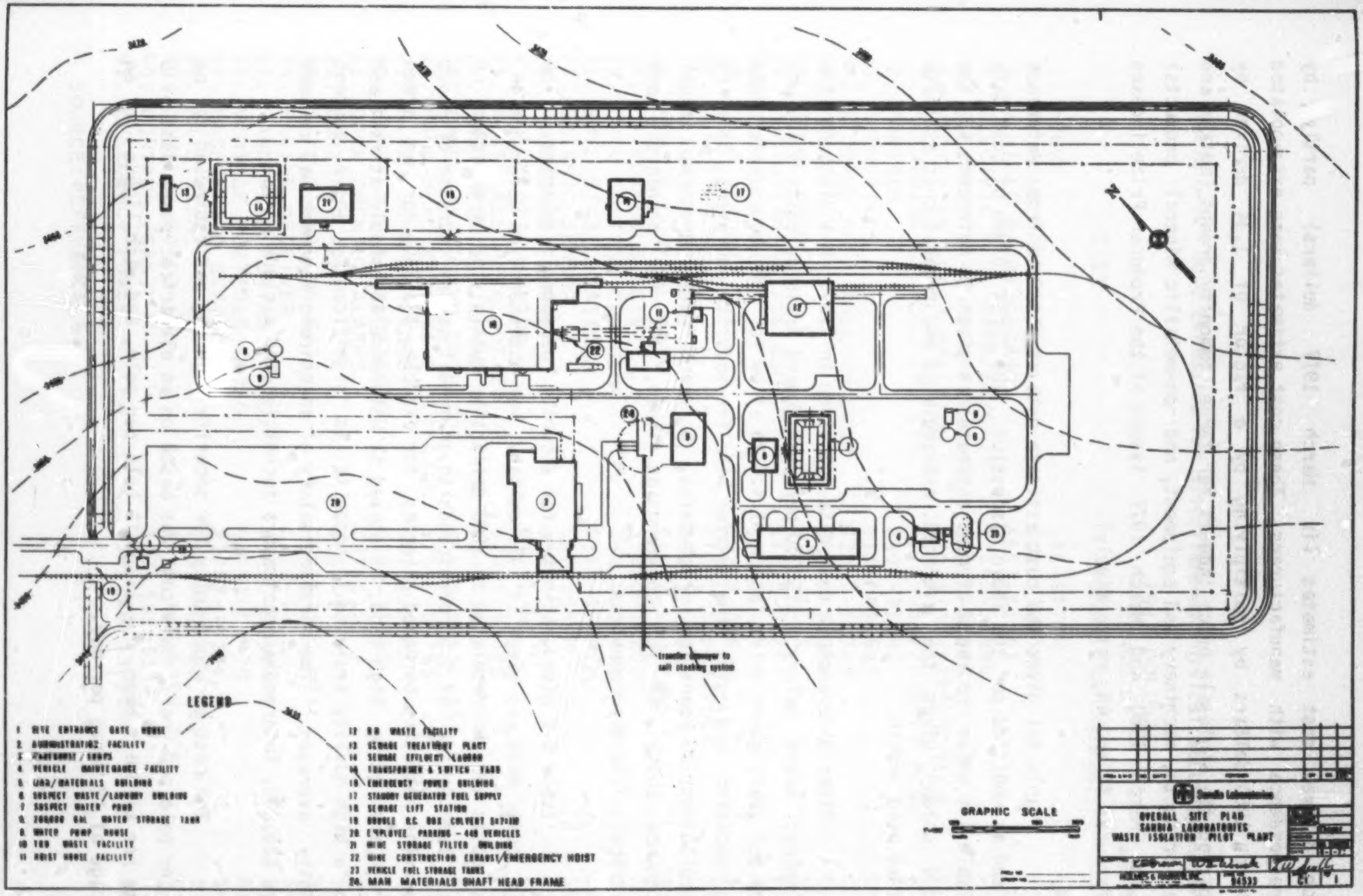

LEGEND
1 SITE ENTRANCE GATE HOUSE
2 ADMINISTRATION FACILITY
3 WAREHOUSE / SHOPS
4 VEHICLE MAINTENANCE FACILITY
5 LAB/MATERIALS BUILDING
6 SUSPECT WASTE/LAUNDRY BUILDING
7 SUSPECT WATER POND
8 200000 GAL WATER STORAGE TANK
9 WATER PUMP HOUSE
10 TRU WASTE FACILITY
11 HOIST HOUSE FACILITY
12 D.H. WASTE FACILITY
13 SEWAGE TREATMENT PLANT
14 SEWAGE EFFLUENT LAGOON
15 TRANSFORMER & SWITCH YARD
16 EMERGENCY POWER BUILDING
17 STANDBY GENERATOR FUEL SUPPLY
18 SEWAGE LIFT STATION
19 DOUBLE R.C. BOX CULVERT
20 EMPLOYEE PARKING - 440 VEHICLES
21 MINE STORAGE FILTER BUILDING
22 MINE CONSTRUCTION EXHAUST/EMERGENCY HOIST
23 VEHICLE FUEL STORAGE TANKS
24. MAN MATERIALS SHAFT HEAD FRAME
Transfer conveyor to salt stacking system
N
GRAPHIC SCALE
Sandia Laboratories
OVERALL SITE PLAN
SANDIA LABORATORIES
WASTE ISOLATION PILOT PLANT
HOLMES & NARVER, INC.
84533
C1
1

Figure 5-3. WIPP surface facility layout

which derived cost estimates (in March 1977 dollars) partly by correspondence with manufacturers. These cost estimates were extrapolated to March 1980 dollars by multiplying by a factor of 1.34 derived by comparing the wholesale price indexes for three commodity groups (metals and metal products, machinery and equipment, and non-metallic mineral products) in the March 1980 and March 1977 issues of the Producer Price indexes (References 44 and 45, respectively).

Table 5-1 gives the cost estimate data as obtained from Reference 43 and as modified per the above discussion. The first column of cost data in Table 5-1 shows the range of cost estimates as given in Reference 43, the second column gives the averaged, extrapolated and rounded cost estimate data as used herein.

Other Reference 43 cost data not given in Table 5-1 include the following: Guard salary, $15,000 per year; guard training costs $1400 per guard per year; guard shift factor of 4.6 to allow for 168 hours/week duty plus vacation and sick time; useful life for security equipment: 35 years for buildings, 10 years for electronics, 6 years for computers; annual mantenance costs: 2% for construction items, 10% for mechanical and electrical, 7.5% for computers.

Table 5-2 gives estimates for security personnel salaries. The basic cost data, as given in 1975 dollars, was obtained from Reference 46. These costs were extrapolated to 1980 dollars by multiplying by a factor of 1.5. The factor of 1.5 corresponds to an annual salary increase of about 8.5%. The resulting burdened salaries, for example, $33,750 for an armed guard, are quite high and, as stated in Reference 46, should attract and keep "a high quality individual since it is significantly above current industry averages." The burdened salary of an unarmed watchman was assumed to be $25,000, intermediate between a technician and a clerk.

The cost of electricity for security lighting was estimated to be $40 per pole per year. This cost was based on an electrical power cost of 6 cents per kilowatt hour, one 150 watt bulb per pole, and with lights on an average of 12 hours per day.

Table 5-1. Cost Estimates for Miscellaneous Physical Security Apparatus

ITEM	1977 DOLLARS RANGE OF SOURCE ESTIMATES*	1980 DOLLARS VALUE USED
1. FENCE	$56-$77/M	$89/M
2. VEHICLE BARRIER/RAILS	$195-$250/M	$300/M
3. VEHICLE BARRIER/GATE	$661-$1363	$1350
4. ELECTRIC VEH. BARRIER/GATE	$1742-$2996	$3150
5. ELECTRIC TRAIN BARRIER/GATE	$3992-$5986	$6675
6. PROTECTED GUARD POSITION	$72-$136/FTX8FT HIGH	$140/FT
7. HARDENING OF SEC. OP. CTR.	$275-$547/FTX8FT HIGH	$550/FT
8. PORTALS	$992-$1340	$1550
9. TURNSTILES	$1156-$1695	$1900
10. STORAGE AREA ROLLING DOOR	$2002-$2702	$3150
11. EMERGENCY EXIT	$2079-$2946	$3350
12. STEEL GRIDS	$108-$138	$165
13. PHOTO-LAMINATING EQUIP.	$1075-$1760	$1900
14. EXCHANGE BADGE	$2-$2.70	$3
15. CARD READER	$2218-$2922	$3450
16. LIGHTING	$1160-$1523/POLE	$1800
17. ALARM/ASSESSMENT CCTV	$6250-$9189	$10,325
18. REMOTE CONTROL CCTV	$9339-$13,704	$15,400
19. FIXED FOCUS CCTV	$3280-$4209	$5,000
20. CCTV CONTROL CONSOLE	$44,406-$71,410	$77,500
21. SOIL STABILIZATION	$112-$144/M	$170/M
22. SEISMIC SENSOR	$47-$94/M	$95/M
23. MICROWAVE SENSOR	$21-$27/M	$32/M
24. VOLUMETRIC SENSOR	$\$3$-$\$4/\text{M}^2$	$\$4.75/\text{M}^2$
25. FIXED ALL METAL DETECTOR	$2498-$3306	$3900
26. HAND-HELD ALL METAL DETECTOR	$202-287	$325
27. FIXED EXPLOSIVE DETECTOR	$14,260-$26,392	$27,000
28. HAND-HELD EXPLOSIVE DETECTOR	$7515-$9775	$11,500
29. FIXED SSNM DETECTOR	NOT QUOTED	N.Q.
30. HAND-HELD SSNM DETECTOR	$900-$1598	$1670
31. DOOR OPENING ALARMS	$97-$167	$175
32. DURESS ALARM	$590-$753	$900
33. SITE SIGNALING SYSTEM	$6450-$13,432	$13,300
34. PAGING RECEIVER	$278-$436	$475
35. HAND-HELD PORTABLE RADIO	$1011-$1374	$1600
36. VEHICLE PORTABLE RADIO	$1143-$1679	$1900
37. BASE RADIO STATION	$2788-$4232	$4700
38. PA SYSTEM	$16,740-$28,061	$30,000
39. CONTROL (CAS)	$214,000-$366,275	$388,000
40. CONTROL (SAS)	$51,300-$134,500	$124,000
41. EMERGENCY POWER	$36,200-$54,800	$61,000

* SOURCE: REFERENCE 43

Table 5-2. Personnel Salary Unit Cost Estimate

JOB CATEGORY	BASIC SALARY* (1975 Dollars)	BURDENED SALARY* (1975 Dollars)	BURDENED SALARY (1980 Dollars)
Security and Reserve Forces			
Supervisor	$18,500	$27,000	$40,500
Guards	15,000	22,500	33,750
Technicians	14,900	22,400	33,600
Clerks	9,000	14,000	21,000
Material Accounting			
Supervisor	22,500	33,750	50,625
Accountants	15,000	22,500	33,750
Clerks	9,000	14,000	21,000

* Data from Reference 47

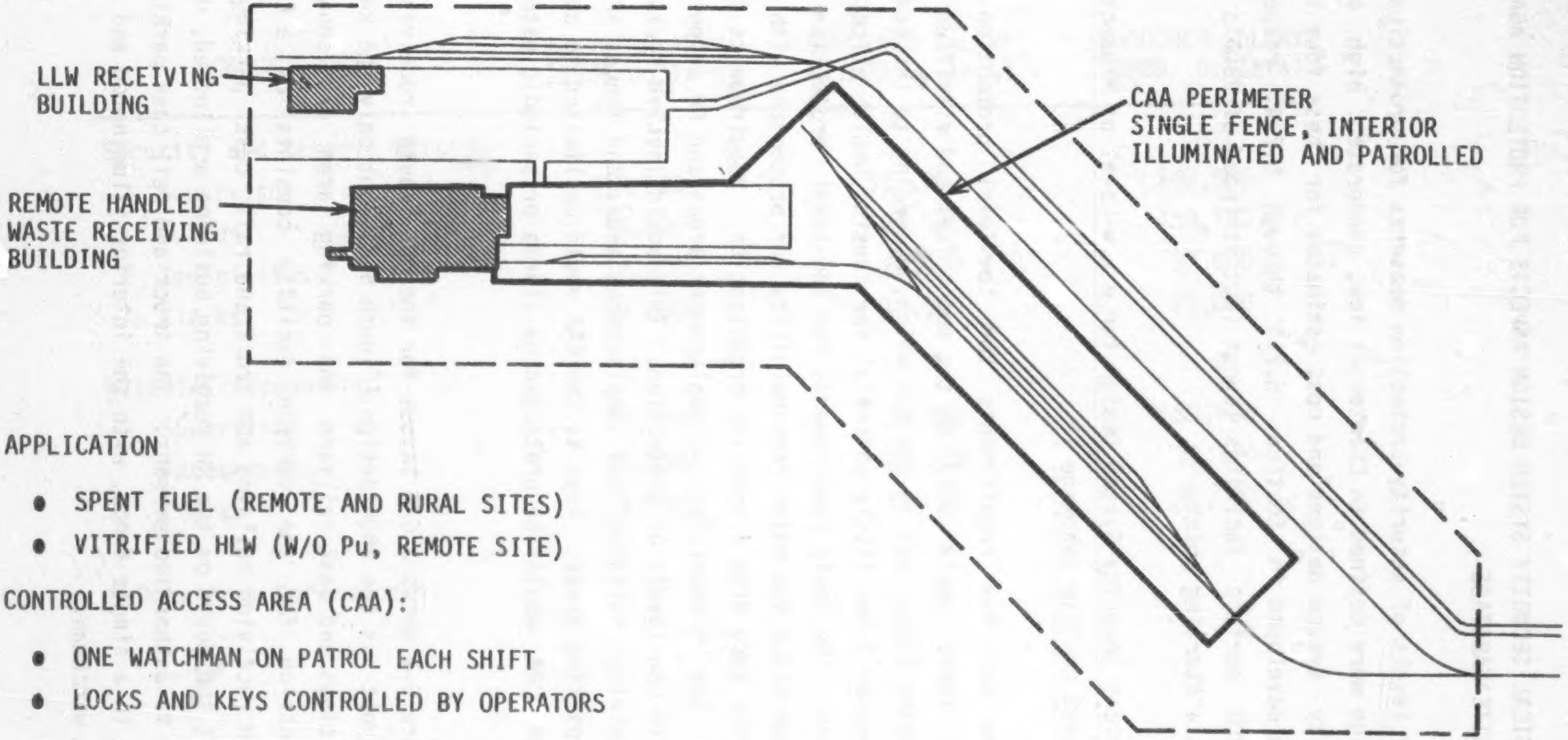
5.2 PHYSICAL SECURITY SYSTEM DESIGN ASPECTS FOR PROTECTION AGAINST ON-SITE SABOTAGE

Four levels of security protection measures for protection against on-site sabotage were defined in Chapter 4: low, moderate, high and very high. Security system designs and cost estimates for these four levels of protection are developed in Sections 5.2.1 through 5.2.4, respectively, using the PBQD surface facilites layout (but stripped of PBQD's security provisions) as a starting point.

5.2.1 Physical Security System Design for a Low-Level of Protection Against On-Site Sabotage

There are few requirements for low-level protection against sabotage, and these apply only to the spent fuel and vitrified (w/o Pu, desert site) waste forms, not to the LLW which, according to the consequence results of Chapter 3 has little potential for causing health effects in the local population. The basic requirements for low-level protection against on-site sabotage place the major responsibility for protection with the site operations rather than with a security organization. Requirements call for protection of the RH receiving and emplacement areas and RH shipping casks in the yard with CAA levels of protection. This would involve locks on the RH waste receiving building and emplacement areas and fences around the shipping cask parking areas. Keys to the CAA would be limited to authorized operators; the CAA would be protected by alarms or periodic patrols when unoccupied.

Figure 5-4 shows a CAA layout for the RH waste receiving area. The basic layout is the PBQD design (Figure 5-2), but only the RH and LLW receiving buildings and cask railyard and parking area are shown. The physical protection for the surface facility consists of a CAA which includes the RH receiving building and truck and rail cask parking areas. This means that the doors on the RH receiving building are locked, with keys available only to authorized persons. The truck and rail cask parking areas are enclosed in a single fence, with the interior illuminated and randomly patrolled by a watchman.


LLW RECEIVING BUILDING
REMOTE HANDLED WASTE RECEIVING BUILDING
CAA PERIMETER SINGLE FENCE, INTERIOR ILLUMINATED AND PATROLLED

APPLICATION

- SPENT FUEL (REMOTE AND RURAL SITES)
- VITRIFIED HLW (W/O Pu, REMOTE SITE)

CONTROLLED ACCESS AREA (CAA):

- ONE WATCHMAN ON PATROL EACH SHIFT
- LOCKS AND KEYS CONTROLLED BY OPERATORS

Figure 5-4. Safeguards system design to provide low level of protection against sabotage (on-site dispersal).

The subsurface RH waste emplacement area is also within the CAA, and is similarly controlled by locks to which only the authorized employees have keys. It is assumed here that the LLW emplacement area is separate from the RH emplacement area. If the two emplacement areas (LLW and RH) cannot easily be physically separated, for example, if RH emplacement rooms are backfilled wth LLW, their access by the LLW shaft will need to be similarly controlled.

This also assumes that the RH emplacement area is physically separated from any area where excavation activities are ongoing. It is expected, based on WIPP and PBQD design information, that there will be ventilation system barriers between emplacement and excavation areas because of the need to prevent HEPA filter saturation from mining activity generated dust. The ventilation barriers must be upgraded, as necessary, to suffice as a CAA boundary.

The estimated cost for the low-level physical security system is derived in Table 5-2. To assure full time coverage by one roving watchman, five watchmen are hired (shift factor of 4.6 rounded up to 5) at an estimated burdened salary of $25,000. The security apparatus includes the CAA (fence, locks, gates) and a security vehicle. Installation costs, annualized installation costs (installation cost divided by item life in years) and operation and maintenance (O&M) costs are cumulated. The cumulated installation cost is about $277,000; the cumulated O&M cost is about $150,00, and the total annual cost is about $175,000.

Table 5-3 includes two sets of truck and personnel gates: one set for the surface facility and one for the emplacement area part of the CAA. Since the men and materials (M&M) shaft serves both the emplacement and mining areas, gates are needed between the base of the M&M shaft and the emplacement area. Like the gates and doors in the RH surface facility, these gates will be used only by authorized persons with appropriate keys. Table 5-3 also includes one security vehicle. The estimated annual O&M costs for that vehicle are $1,000 (10%) maintenance plus $1,800 operating based on a estimated 10,000 miles at 18 cents per mile.

Table 5-3. Estimated Costs for Low-Level Security Protection Against Sabotage (On-Site Dispersal)

ITEM	COST BASIS	INSTALLATION COST	LIFE	ANNUALIZED COST	OPERATION AND MAINTENANCE COST
WATCHMAN (1)	5X$25,000	$ -	-	$ -	$125,000
RH BLDG LOCKS (10)	$50 EACH	500	10 YRS	50	50
CAA FENCE (1600 M)	$89/M	142,400	10 YRS	14,240	2,848
CAA LIGHTS (60 POLES)	$1800/POLE	108,000	10 YRS	10,800	10,800
ELECTRICITY	$40/YR/POLE	-	-	-	2,400
TRAIN GATE	$6675	6,675	10 YRS	668	668
TRUCK GATE (2)	$3150 EACH	6,300	10 YRS	630	630
PERSONNEL GATE (2)	$1550	3,100	10 YRS	310	310
SECURITY VEHICLE	$10,000	10,000	10 YRS	1,000	2,800
TOTALS		$276,975		$ 27,698	$145,506

TOTAL ANNUAL COST ------ $175,000

5.2.2 Physical Security System Design for a Moderate Level of Protection Against On-Site Sabotage

The security measures for a moderate level of protection against on-site sabotage are similar to those for the low level of protection just discussed, i.e., CAA protection of RH receiving building, emplacement area and parking area. The additional measures for a moderate level of protection are the following: a security organization with a 40 hour per week security supervisor and a few (2-3) watchmen per shift, security organization responsibility for protection against on-site sabotage with such measures as occasional patrols and random search of incoming persons, vehicles and packages, a badging system, and illuminated CAA.

The CAA for a moderate level of protection can be the same as for the low level of protection, i.e., locked doors on the RH receiving building plus a fenced truck and rail cask parking area. However, for a moderate level of protection, entry is monitored by watchmen, who perform random searches of entering persons, packages and vehicles. To minimize the number of watchmen required to monitor entry, the reference CAA design included only one surface-level entrance. In the reference design (Figure 5-5), the entrance is a door in the RH receiving building. For this design, a watchman would need to walk or drive to the train gate at the far end of the fenced area whenever a train enters or departs the CAA.

Table 5-4 shows the estimated costs for the moderate level of physical security protection. Fourteen watchmen are required to assure that there are three watchmen on duty at all times* (shift factor of 4.6). In addition, a security supervisor is included. The CAA costs (fences, gates, lighting) are similar except for the addition of a gatehouse. Additional security apparatus include a badge machine, portable radios and portable weapon and explosive detectors. The total installation cost for this equipment is about $350,000; the annual O&M cost is about $420,000.

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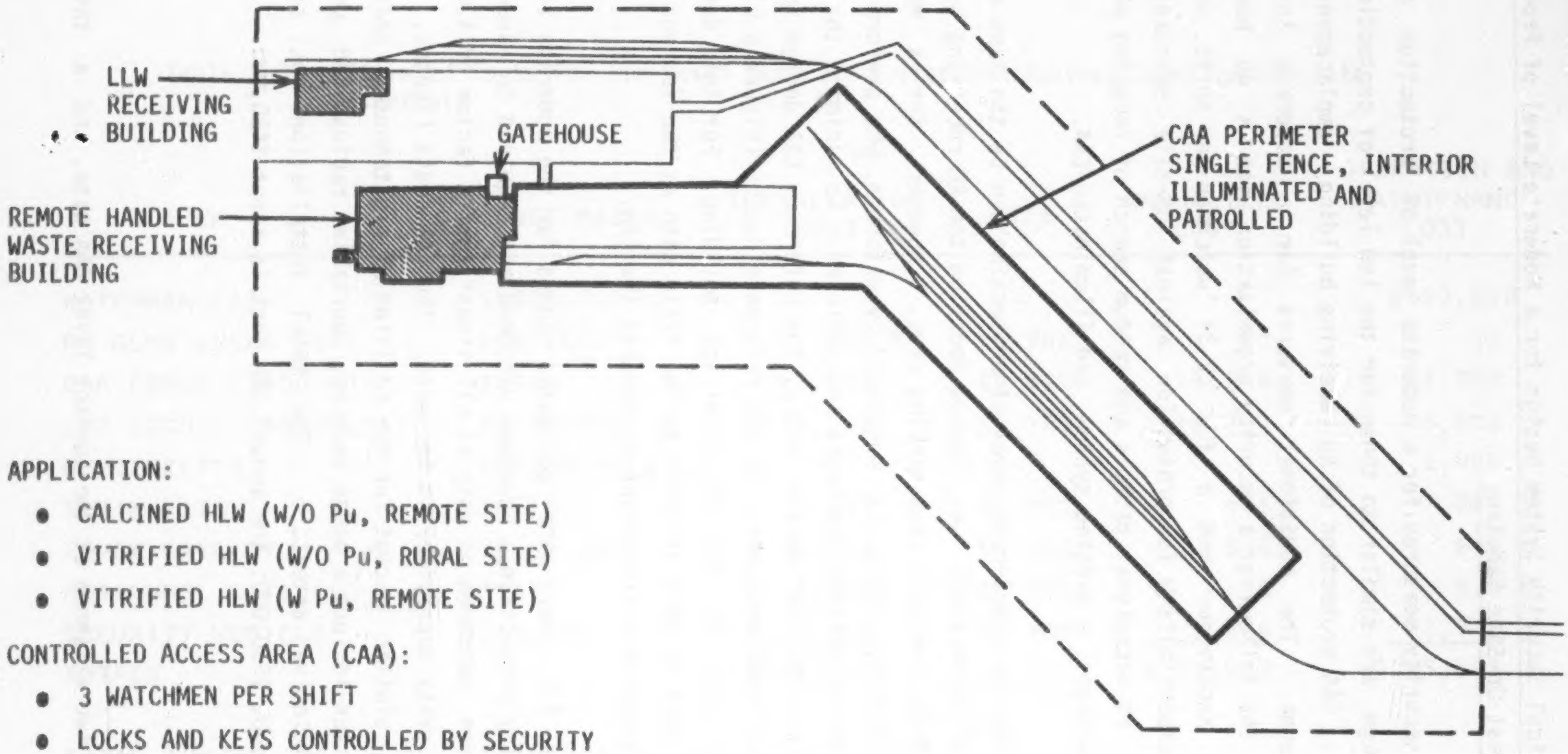
* This permits two watchmen at the surface level CAA gate, and a third on patrol.


LLW RECEIVING BUILDING
GATEHOUSE
REMOTE HANDLED WASTE RECEIVING BUILDING
CAA PERIMETER SINGLE FENCE, INTERIOR ILLUMINATED AND PATROLLED

APPLICATION:

- CALCINED HLW (W/O Pu, REMOTE SITE)
- VITRIFIED HLW (W/O Pu, RURAL SITE)
- VITRIFIED HLW (W Pu, REMOTE SITE)

CONTROLLED ACCESS AREA (CAA):

- 3 WATCHMEN PER SHIFT
- LOCKS AND KEYS CONTROLLED BY SECURITY
- RANDOM SEARCH OF ENTERING PERSONNEL, PACKAGES, VEHICLES

Figure 5-5. Safeguards system design to provide moderate level of protection against sabotage (on-site dispersal).

Table 5-4. Estimated Costs for Moderate Level of Security Protection Against Sabotage (On-Site Dispersal)

ITEM	COST BASIS	INSTALLATION COST	LIFE	ANNUALIZED COST	OPERATION AND MAINTENANCE COST
SECURITY SUPERVISOR	$40,500	$ -	-	$ -	$40,500
WATCHMEN (3)	14X$25,000	-	-	-	350,000
CAA FENCE (1600 M)	$89/M	141,600	10 YRS	14,160	2,832
RH BLDG LOCKS (10)	$50 EACH	500	10 YRS	50	50
CAA LIGHTING (60 POLES)	$1800/POLE	108,000	10 YRS	10,800	10,800
ELECTRICITY	$40/POLE/YR	-	-	-	2,400
TRUCK GATE (2)	$3150 EACH	6,300	10 YRS	630	630
TRAIN GATE	$6675	6,675	10 YRS	668	668
PERSONNEL GATE (2)	$1550 EACH	3,100	10 YRS	310	310
REMOTE GATE CONTROL	$12,000	12,000	10 YRS	1,200	1,200
BADGE MACHINE	$1900	1,900	10 YRS	190	190
PORTABLE RADIOS (3)	$1600 EACH	4,800	10 YRS	480	480
HAND-HELD WEAPON DETECTORS (2)	$325 EACH	650	10 YRS	65	65
GATEHOUSE (5X10M)	$400/M^2	20,000	35 YRS	571	400
HAND-HELD EXPLOSIVES DETECTORS (2)	$11,500 EACH	23,000	10 YRS	2,300	2,300
SECURITY VEHICLES (2)	$10,000 EACH	20,000	10 YRS	2,000	5,600
TOTALS		$ 348,525		$ 33,424	$418,425

TOTAL ANNUAL COST --------- $450,000

5.2.3 Physical Security System Design for a High Level of Protection Against On-Site Sabotage

The security measures for a high level of protection against on-site sabotage differ from those for a moderate level of protection largely by addition of a double PA barrier with isolation zone and by the substitution of armed and trained guards for the watchmen.

Figure 5-6 shows where the PA and VA perimeters might lie on the PBQD surface facility design. The PA perimeter might enclose both the RH and LLW receiving buildings and parking areas, and the VA perimeter might enclose the same area included in the CAA for the moderate level of security protection. In addition, there will be a central alarm station (CAS). This CAS need not be hardened, and might be co-located with the PA perimeter gatehouse.

In this design, access to the PA would be controlled by armed guards. Access to the VA could, like access to the CAA for the low level of protection, be controlled by the operators, thus no VA gatehouse is shown in Figure 5-6.

Table 5-5 compiles the costs for a high level of security protection. Twenty-three armed guards are employed to provide a coverage of five guards at all times. In addition, there are five shift security supervisors plus one day security supervisor.* The perimeter costs are increased significantly because of the additional fencing, alarms, gates and gatehouse. Also an alarm station and emergency power supply are added. The alarm station is assumed to be co-located with the main gatehouse; therefore, the main gatehouse has been increased in size from 5x10 meters to 10x15 meters. Three vehicles and three personnel gates are included as penetrations to the PA, the surface level VA and the emplacement level VA. One portable weapon detector and one portable explosives detector for each

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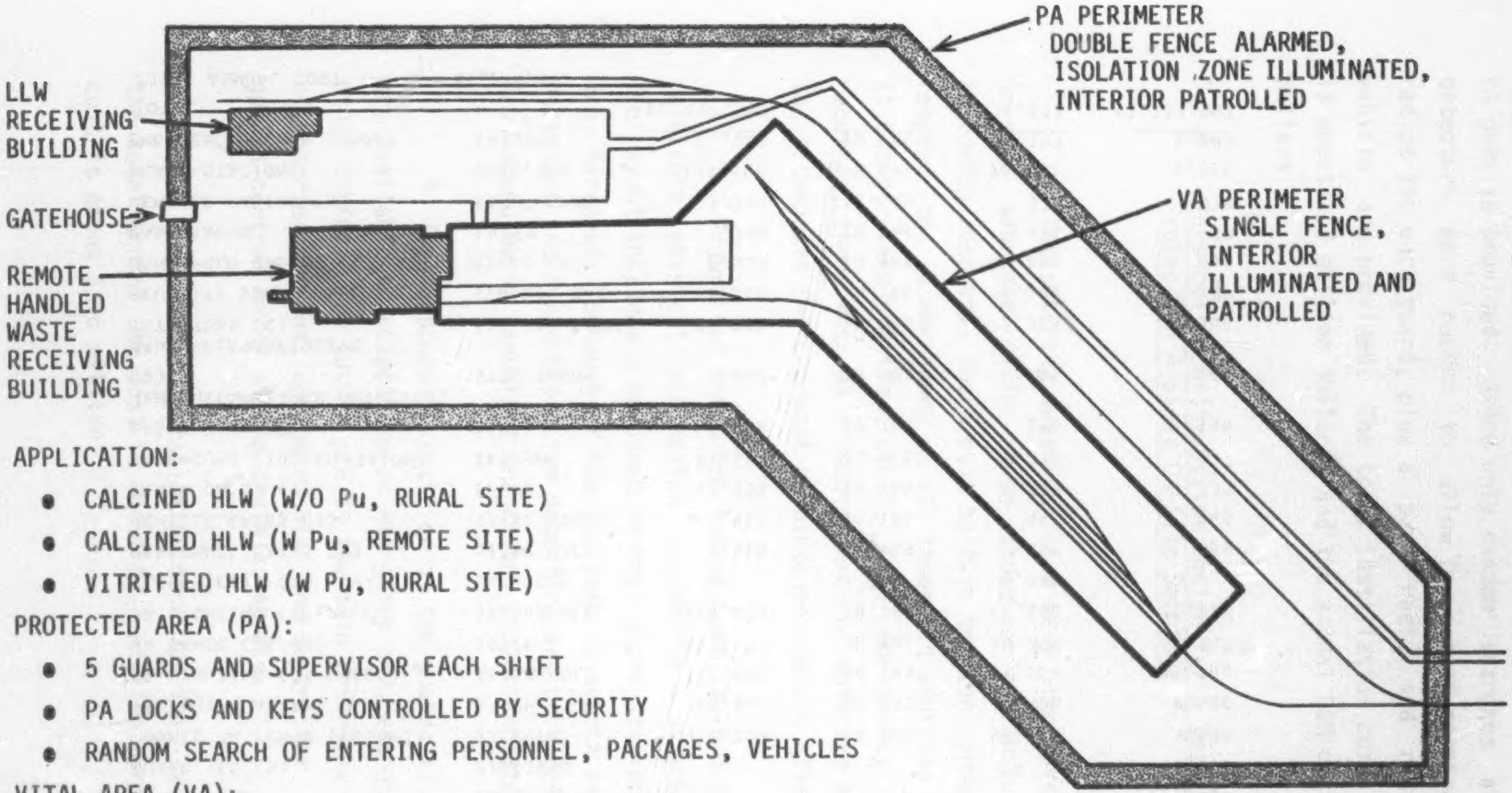
* Assumed guard dispostion is two at main gate, one plus supervisor at CAS, two on patrol and train gate. Entry to emplacement area is controlled by guards at main gate using remote entry control equipment.


PA PERIMETER
DOUBLE FENCE ALARMED, ISOLATION ZONE ILLUMINATED, INTERIOR PATROLLED
LLW RECEIVING BUILDING
GATEHOUSE
VA PERIMETER
SINGLE FENCE, INTERIOR ILLUMINATED AND PATROLLED
REMOTE HANDLED WASTE RECEIVING BUILDING

APPLICATION:

- CALCINED HLW (W/O Pu, RURAL SITE)
- CALCINED HLW (W Pu, REMOTE SITE)
- VITRIFIED HLW (W Pu, RURAL SITE)

PROTECTED AREA (PA):

- 5 GUARDS AND SUPERVISOR EACH SHIFT
- PA LOCKS AND KEYS CONTROLLED BY SECURITY
- RANDOM SEARCH OF ENTERING PERSONNEL, PACKAGES, VEHICLES

VITAL AREA (VA):

- VA LOCKS AND KEYS CONTROLLED BY OPERATORS

COMMUNICATIONS:

- CAS
- RADIO AND TELEPHONE TO LLEA

Figure 5-6. Safeguards system design to provide high level of protection against sabotage (on-site dispersal).

Table 5-5. Estimated Costs for High Level of Security Protection Against Sabotage (On-Site Dispersal)

ITEM	COST BASIS	INSTALLATION COST	LIFE	ANNUALIZED COST	OPERATION AND MAINTENANCE COST
DAY SECURITY SUPERVISOR	$40,500	$ -	-	$ -	$ 40,500
SHIFT SECURITY SUPERVISOR	5X$40,500	-	-	-	202,500
GUARDS (5)	23X$33,750	-	-	-	776,250
GUARD T&Q (5)	23X$1865	-	-	-	42,895
DOUBLE PA FENCE (2650M)	2X$89/M	471,700	10 YRS	47,170	9,434
PERIMETER ALARMS	$32/M	84,800	10 YRS	8,480	8,480
PA LIGHTING (65 POLES)	$1800/POLE	117,000	10 YRS	11,700	11,700
VA FENCE (1600M)	$89/M	142,400	10 YRS	14,240	2,848
VA LIGHTING (60 POLES)	$1800/POLE	108,000	10 YRS	10,800	10,800
ELECTRICITY (PA + VA)	$40/POLE	-	-	5,000	-
PERSONNEL GATES (3)	$1550 EACH	4,650	10 YRS	465	465
VEHICLE GATES (3)	$3150 EACH	9,450	10 YRS	945	945
TRAIN GATES (2)	$6675	13,350	10 YRS	1,335	1,335
GATEHOUSE (10X15M+5X10M)	\$400/M^{2}	80,000	35 YRS	2,285	1,600
BADGE MACHINE	$1900	1,900	10 YRS	190	190
HAND-HELD WEAPON DETECTORS (2)	$325 EACH	650	10 YRS	65	65
HAND-HELD EXPLOSIVE DETECTORS (2)	$11,500 EACH	23,000	10 YRS	2,300	2,300
SECURITY VEHICLES (3)	$10,000 EACH	30,000	10 YRS	3,000	8,400
HAND-HELD RADIOS (5)	$1600 EACH	8,000	10 YRS	800	800
BASE RADIO	$4700	4,700	10 YRS	470	470
VEHICLE RADIOS (3)	$1900 EACH	5,700	10 YRS	570	570
ALARM STATION	$124,000	124,000	6 YRS	20,667	9,300
EMERGENCY POWER SUPPLY	$61,000	61,000	10 YRS	6,100	6,100
TOTAL		$1,290,300		$136,582	$1,137,947
TOTAL ANNUAL COST ------- $1,275,000					

VA gate is provided. Since only random searches are required, no extra detectors were needed to allow for out-of-service units. Last, portable radios for each guard, plus a base radio and radios for each security vehicle are provided. The total installation cost for this security system is about 1.3 million dollars, and the annual O&M cost is about 1.1 million dollars.

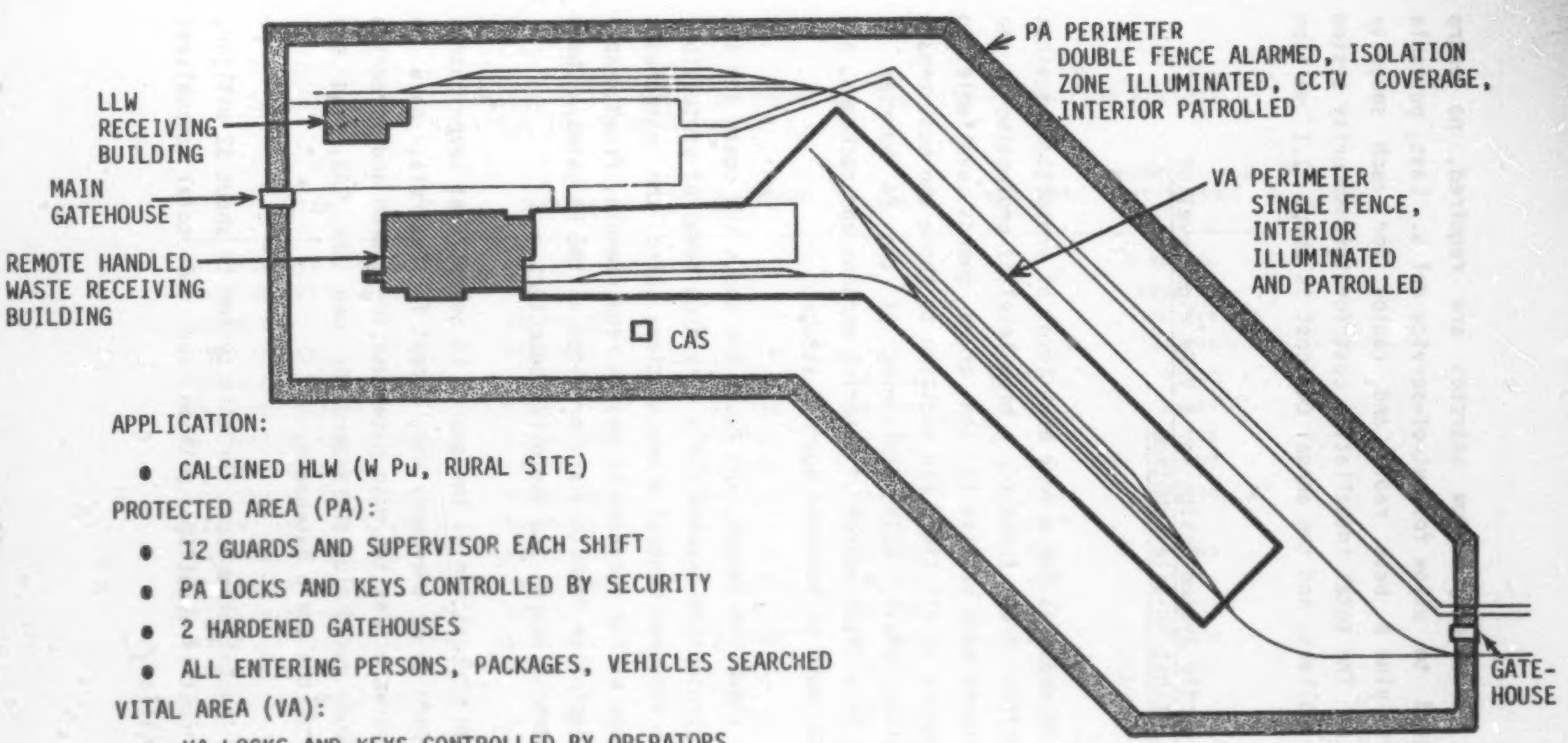
5.2.4 Physical Security System Design for a Very High Level of Protection Against On-Site Sabotage

The security measures for a very high level of protection against on-site sabotage differ from those for a high level of protection in the following respects: there must be five to ten armed guards available to respond to an emergency at all times (in addition to those who must remain at gates, alarm stations, etc.), CCTV monitoring of the PA barrier is required, there must be a total search of entering persons and packages, and the gatehouses and CAS must be hardened against attack.

Figure 5-7 shows the layout, and Table 5-6 shows the costs for the reference physical protection system for a very high level of protection. The layout includes a hardened central alarm station; also the gatehouses are hardened. Because of the increase in search requirements, fixed weapon detectors and fixed explosive detectors are provided at the PA gates. These are backed up by hand-held weapon and explosive detectors.

The assumed disposition of the guards is as follows: Seven guards are available to respond to an emergency and, except for patrols, have no other duties. Two guards are at the main gatehouse for search and screening of entering persons, one guard plus the supervisor man the CAS, and two guards control entry at the train gatehouse.

The total installation cost for this system is about $2 million, the total annual O&M cost is about $2.3 million, and the total annualized cost is about $2.6 million.


LLW RECEIVING BUILDING
MAIN GATEHOUSE
REMOTE HANDLED WASTE RECEIVING BUILDING
CAS
PA PERIMETER
DOUBLE FENCE ALARMED, ISOLATION ZONE ILLUMINATED, CCTV COVERAGE, INTERIOR PATROLLED
VA PERIMETER
SINGLE FENCE, INTERIOR ILLUMINATED AND PATROLLED
GATE-HOUSE

APPLICATION:
- CALCINED HLW (W Pu, RURAL SITE)

PROTECTED AREA (PA):
- 12 GUARDS AND SUPERVISOR EACH SHIFT
- PA LOCKS AND KEYS CONTROLLED BY SECURITY
- 2 HARDENED GATEHOUSES
- ALL ENTERING PERSONS, PACKAGES, VEHICLES SEARCHED

VITAL AREA (VA):
- VA LOCKS AND KEYS CONTROLLED BY OPERATORS

COMMUNICATIONS:
- CAS (HARDENED) AND SAS
- RADIO AND TELEPHONE TO LLEA

Figure 5-7. Safeguards system design to provide very high level of protection against sabotage (on-site dispersal).

Table 5-6. Estimated Costs for Very High Level of Security Protection Against Sabotage (On-Site Dispersal)

ITEM	COST BASIS	INSTALLATION COST	LIFE	ANNUALIZED COST	OPERATION AND MAINTENANCE COST
DAY SECURITY SUPERVISOR	\$ 40,500	\$ -	-	\$ -	\$ 40,500
SHIFT SECURITY SUPERVISOR	5X\$40,500	-	-	-	202,500
GUARDS (12)	55X\$33,750	-	-	-	1,856,250
GUARD T&Q (12)	55X\$1865	-	-	-	102,575
DOUBLE PA FENCE (2650M)	2X\$89/M	471,700	10 YRS	47,170	9,434
PERIMETER ALARMS	\$32/M	84,800	10 YRS	8,480	8,480
CCTV (15)	\$5000	75,000	10 YRS	7,500	7,500
PA LIGHTING (65 POLES)	\$1800/POLE	117,000	10 YRS	11,700	11,700
VA FENCE (1600 M)	\$89/M	142,400	10 YRS	14,240	2,848
VA LIGHTING (60 POLES)	\$1800/POLE	108,000	10 YRS	10,800	10,800
ELECTRICITY (PA & VA)	\$40/POLE	-	-	5,000	-
PERSONNEL GATES (3)	\$1550 EACH	4,650	10 YRS	465	465
VEHICLE GATES (3)	\$3150 EACH	9,450	10 YRS	945	945
TRAIN GATES (2)	\$6675 EACH	13,350	10 YRS	1,335	1,335
HARDENED GATEHOUSES (2)	\$400/M^2+\$550/FT	142,500	35 YRS	4,072	2,850
BADGE MACHINE	\$1900	1,900	10 YRS	190	190
FIXED WEAPON DETECTOR (2)	\$3900 EACH	7,800	10 YRS	780	780
HAND-HELD WEAPON DETECTORS (2)	\$325 EACH	650	10 YRS	65	65
FIXED EXPLOSIVE DETECTORS (2)	\$27,000 EACH	54,000	10 YRS	5,400	5,400
HAND-HELD EXPLOSIVE DETECTORS (2)	\$11,500 EACH	23,000	10 YRS	2,300	2,300
SECURITY VEHICLES (4)	\$10,000 EACH	40,000	10 YRS	4,000	11,200
HAND-HELD RADIOS (10)	\$1600 EACH	16,000	10 YRS	1,600	1,600
BASE RADIO (2)	\$4700 EACH	9,400	10 YRS	940	940
CAS STRUCTURE (5X10M)	\$400/M^2+\$550/FT	75,000	35 YRS	2,143	1,500
CAS CONTROL	\$388,000	388,000	6 YRS	64,667	29,100
SAS CONTROL	\$124,000	124,000	6 YRS	20,667	9,300
EMERGENCY POWER SUPPLY	\$61,000	61,000	10 YRS	6,100	6,100
TOTALS		\$1,969,600		\$ 220,559	\$2,326,657

TOTAL ANNUAL COST --------- \$2,550,000

5.3 PHYSICAL SECURITY SYSTEM DESIGN ASPECTS FOR PROTECTION AGAINST THEFT/SABOTAGE

Section 5.2 described physical security protection measures for various levels of protection against on-site sabotage. As discussed in Chapter 4, additional measures must be taken to protect against the threat of theft for the purpose of off-site dispersal. The reason for the additional measures is obvious: the measures for protection against on-site sabotage protects largely against intrusion by an outsider and transport of weapons and explosives to the facility. They do little to protect against the unauthorized removal of waste.

Four levels of security protection measures for protection against theft/off-site dispersal were defined in Chapter 4, i.e., low, moderate, high and very high. These levels of protective measures do not correlate precisely with the levels of protection measures specified for protection against on-site sabotage, as is shown in Table 5-7, which summarizes the level of protection specifications for the various waste forms. For example, a spent-fuel repository at a desert site requires only a low level of physical security protection against on-site sabotage, but requires a moderate level of protection against theft/sabotage.

As shown in Table 5-7, measures for a low level of protection against theft/sabotage apply to ILW and LLW, while measures for the moderate, high and very high levels apply to the other waste forms. For all waste forms, the level of protection specified for protection against theft/sabotage is either the same as or is one level above the level of protection specified for protection against on-site sabotage.

The security levels for all four levels of protection against theft/sabotage have the same objective, that of timely detection and reporting (to LLEA) of the theft of waste material. This is accomplished by monitoring the appropriate exits as specified in Table 4-7,. As indicated by Table 4-7, protection against theft/sabotage requires only a few measures in addition to the ones required for protection against on-site sabotage.

Table 5-7. Levels of Protection Associated with Waste Types and Repository Location for Protection Against Onsite Sabotage and Theft/Sabotage

WASTE TYPE AND SITE LOCATION	LEVEL OF PROTECTION REQUIRED VERSUS ONSITE SABOTAGE	LEVEL OF PROTECTION REQUIRED VERSUS THEFT/SABOTAGE
Calcined HLW w Pu Rural Site	Very High	Very High
Calcined HLW w Pu Remote Site	High	Very High
Vitrified HLW w Pu Rural Site	High	High
Calcined HLW w/o Pu Rural Site	High	High
Vitrified HLW w Pu Remote Site	Moderate	High
Vitrified HLW w/o Pu Rural Site	Moderate	Moderate
Calcined HLW w/o Pu Remote Site	Moderate	High
Spent Fuel Rural Site	Low	Moderate
Vitrified HLW w/o Pu Remote Site	Low	Moderate
Spent Fuel Remote Site	Low	Moderate
ILW & LLW	None	Low

The specific measures and associated costs for each of the postulated waste repositories are discussed below.

5.3.1 Calcined HLW (w Pu) Repository at Rural Site

For this repository, as indicated by Table 5-7, a high level of protection is required for protection against both on-site sabotage and theft/sabotage. According to the proposed requirements in Table 4-7, no modifications to the basic physical security system design would be required; however, existing guards at the PA portals would be required to check all exiting vehicles for unauthorized waste cargo. Shipping casks, which cannot be opened for inspection at the gate, would be checked for seals certifying that they are empty. These seals would be placed on the cask in the cask unloading area by the usual MC&A sealing techniques, i.e., by two authorized operators, one of whom places the seal while the other verifys.

Except for the minor cost of these seals, no additional costs are estimated for protecting this facility against theft/sabotage.

5.3.2 Calcined HLW (w Pu) Repository at Desert Site

According to Table 5-7, this repository requires a high level of protection against on-site sabotage and a very high level of protection against theft/sabotage. The gates on the PA boundary would therefore have to be hardened to be bullet resisting structures. The estimated additional initial cost for this hardening is $132,000 (two structures, one 10x15 meters and the other 5x10 meters). The corresponding additional annualized cost is $3,771, and the estimated additional annual maintenance cost is $2,640.

To guard against unauthorized removal of waste, existing guards at the PA portals would be required to check all exiting vehicles for unauthorized waste cargo. Shipping casks, which cannot be opened at the gate, would be checked for seals certifying that they are empty. These seals would be placed on the cask in the cask unloading area by the usual

MC&A sealing techniques, i.e., by two authorized operators, one of whom places the seal while the other verifys.

5.3.3 Vitrified HLW (w Pu) Repository at Rural Site

According to Table 5-7, this repository requires a high level of protection against both on-site sabotage and theft/sabotage. No modifications to the basic physical security system design would be required; however, existing guards at the PA portals would be required to check all exiting vehicles for unauthorized waste cargo. Shipping casks, which cannot be opened for inspection at the gate, would be checked for seals certifying that they are empty. These seals would be placed on the cask in the cask unloading area by the usual MC&A sealing techniques, i.e., by two authorized operators, one of whom places the seal while the other verifys.

Except for the minor cost of these seals, no additional costs are estimated for protecting this facility against theft/sabotage.

5.3.4 Calcined HLW (w/o Pu) Repository at Rural Site

The discussion given in Section 5.3.3 also applies to this facility.

5.3.5 Vitrified HLW (w Pu) Repository at Desert Site

According to Table 5-7, this repository requires a moderate level of protection against on-site sabotage and a high level of protection against theft/sabotage. Two changes to the design of Section 5.3.2 would need to be made. First, a base radio for communication with LLEA would be needed, at an estimated installation cost of $4,700 (annualized cost $470/year, maintenance cost $470/year). This base radio would logically be located in the CAA gatehouse.

Second, since the design of Section 5.3.2 provides no control for LLW (low level now required per Table 5-7), appropriate locks and fencing needs to be added to provide this protection. The additional protection is as follows: locks for the LLW building (estimated five locks at $50 each), 800 meters of fence to enclose LLW truck parking and railroad siding areas, gates (truck, personnel, and train) for this fence (respective costs $3,150, $1,550, $6,675) also gates (personnel and vehicle at $1,560 and $3,150, respectively) at the M&M access to the LLW emplacement area. These costs are summarized in Table 5-8; the total estimated installation cost is $87,525 and the total estimated annual cost is $11,810.

To guard against unauthorized removal of waste, existing watchmen at the CAA portals would be required to check all exiting vehicles for unauthorized waste cargo. Shipping casks, which cannot be opened for inspection at the gate, would be checked for seals certifying that they are empty. These seals would be placed on the cask in the cask unloading area by the usual MC&A sealing techniques, i.e., by two authorized operators, one of whom places the seal while the other verifys.

5.3.6 Vitrified HLW (w/o Pu) Repository at Rural Site

According to Table 5-7, this repository requires a moderate level of protection against both on-site sabotage and theft/sabotage.

Only one change to the design of Section 5.3.2 (moderate) is required. Since the design of Section 5.3.2 provided no protection for LLW, and a low level of protection is required for LLW per Table 5-7, appropriate locks and fencing would needed to be added to include the LLW receiving area in the CAA. The estimated costs for including the LLW receiving area in the CAA are summarized in Table 5-8; the total estimated additional installation cost is $87,525, and the total estimated additional annualized cost is $11,810.

To guard against unauthorized removal of waste, existing watchmen at the CAA portals would be required to check all exiting vehicles for unauthorized waste cargo. Shipping casks, which cannot be opened for

Table 5-8. Additional Costs to Low and Moderate Onsite Sabotage Designs for Protection of LLW Against Theft/Sabotage

Item	Basis	Installation Cost	Life	Annualized Cost	Operation and Maintenance Cost
Fence (800 m)	$89/m	$71,200	10 yrs	$7,120	$1,425/year
Train gate	$6,675 ea	6,675	"	668	668/year
Vehicle gate (2)	$3,150 ea	6,300	"	630	630/year
Personnel gate (2)	$1,550 ea	3,100	"	310	310/year
Locks (5)	$50 ea	250	"	25	25/year
TOTAL		$87,525		$8,753	$3,057/year

Total Additional Annual Cost - $11,810

inspection at the gate, would be checked for seals certifying that they are empty. These seals would be placed on the cask in the cask unloading area by the usual MC&A sealing techniques, i.e., by two authorized operators, one of whom places the seal while the other verifys.

5.3.7 Calcined HLW (w/o Pu) Repository at Desert Site

The discussion given in Section 5.3.5 also applies to this facility.

5.3.8 Spent-Fuel Repository at Rural Site

According to Table 5-7, this repository requires a low level of protection against on-site sabotage and a moderate level of protection against theft/sabotage.

Table 4-7 indicates that, for a moderate level of protection against theft/sabotage, all exiting vehicles from the RH facility must be released by a watchman who makes random checks for unauthorized waste cargos. This requires the addition of one watchman per shift for an estimated cost of $125,000 (5x$25,000). Also, the LLW receiving area protective measures as discussed in Section 5.3.5 are needed. The total estimated additional installation cost for these measures is $87,525, and the total estimated annualized cost is $136,810.

To guard against unauthorized removal of waste, existing watchmen at the CAA portals would be required to check all exiting vehicles for unauthorized waste cargo. Shipping casks, which cannot be opened for inspection at the gate, would be checked for seals certifying that they are empty. These seals would be placed on the cask in the cask unloading area by the usual MC&A sealing techniques, i.e., by two authorized operators, one of whom places the seal while the other verifys.

5.3.9 Vitrified HLW (w/o Pu) Repository at Desert Site

The discussion given in Section 5.3.8 also applies to this facility.

5.3.10 Spent-Fuel Repository at Desert Site

The discussion given in Section 5.3.8 also applies to this facility.

5.4 PHYSICAL SECURITY SYSTEM DESIGN ASPECTS FOR PROTECTION AGAINST SNM THEFT

As discussed in Chapter 4, one additional safeguards measure to provide deterrence against SNM theft by smuggling it out of a shipper facility in LLW containers is suggested. This measure, which is intended to provide some possibility of detecting removal of the SNM from the repository, is the use of random checks for SNM among persons, packages and vehicles exiting the waste repository.

Such checks would not include hands-on searches of personnel, but would be performed with hand-held SNM detectors. A minimum of two hand-held SNM detectors is recommended in order to provide one spare for repair. The associated installation cost, based on a price of $1670 each, is $3340, and the annualized cost and O&M cost are $334 and $334, respectively.

5.5 ALTERNATIVE PHYSICAL SECURITY MEASURES

A number of alternative physical security measures for the high-level waste repository are possible. Four alternatives, for four different levels of protection, have already been discussed. Other than these four levels of protection alternatives, two major alternative areas have been visualized. The possibility of reducing the protection requirements for interior facilities by protection of the HEPA filters was briefly discussed in Chapter 4. Second, because the major physical security costs are salaries of security personnel, hardware versus personnel tradeoffs are of interest. These two alternative areas are discussed below.

5.5.1 Protection of HEPA Filters

As mentioned in Chapter 4, intact HEPA filters could reduce the consequences associated with interior sabotage events (events in the waste receiving building or emplacement areas) by a factor of 2000. Thus, assured protection of the filters could substitute for protection against on-site sabotage within the waste receiving and emplacement areas. Additionally, the exterior shipping cash storage (truck parking and railroad siding) areas could be protected if these areas were enclosed and vented through the HEPA filters.

Protection of the HEPA filters, by reducing consequences by a factor of 2000, would reduce the protection requirements for on-site sabotage for all waste types and locations considered (see Figure 4-3) to a low level of protection.

The advantage of HEPA filter protection is a possible cost savings and a reduction in the need to perform searches on personnel, packages and vehicles entering the waste receiving and emplacement areas. However, less cost savings than might at first be expected will probably be realized.

The potential cost savings depends on the level of protection otherwise required for the facility. There would be no cost savings for the spent fuel or vitrified HLW (w/o Pu) remote site facilities, for which only a low level of protection is required whether or not the filters are protected. For high-level waste facilities, otherwise requiring a moderate level of protection, protection of the filters could reduce the watchman requirements by one per shift for a corresponding savings of $100,000 per year.* Access to HEPA filters and shipping cask outdoor storage areas would be controlled by watchmen, but access to the RH receiving building and the emplacement areas would be controlled by operators.

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*Originally 3 per shift (or 14 with shift factor of 4.6) at $25,000 for a cost of $350,000. Reduction to 2 per shift (or 10 with shift factor of 4.6) at $25,000 or $250,000 gives net cost reduction of $100,000 per year. Reduction to 1 per shift (5 total) or $125,000 per year would reduce salary costs by $225,000.

If, in addition, the cask parking and railroad siding areas are enclosed and vented through HEPA filters, only one watchman per shift would be required. This would save an additional \$125,000 per year in watchman salary. The cost of enclosing the parking and siding areas could be as much as \$20 million, depending on the size area enclosed. (The \$20 million cost is based on an estimated construction cost of \$500/m^2 and a building area of 40,000 m^2.) The corresponding annualized cost (based on a 35 year life) is \$570,000/year plus \$400,000/year maintenance. Obviously, enclosing the entire cask parking and siding area would not be cost effective for this application.

It is not clear that protection of filters would result in any cost savings to facilities otherwise requiring a high, or very high, level of protection. Since the philosophy for a high, or very high, level of protection is to prevent, rather than to detect, a sabotage event, a force of guards would still be required to protect the filters. Since both the filter area and outside shipping cask storage area would need to be protected, the same equipment (e.g., fence, alarms, lighting, gates) and guards would be required. The same guard disposition would hold, i.e. (for the high level of protection) 2 at the gatehouse, 1 guard plus supervisor at CAA, and two on patrol with visits as necessary to the train gate.

An alternative to protection of the HEPA filters is interruption of the ventilation flow. Interruption of ventilation flow could effectively contain most of the radioactive debris within the facility. The advantage of this approach, relative to protection of the filter, is that it eliminates the need to protect the filter. However, the ventilation flow would need to be interrupted in such a way that the saboteurs could not restore it, e.g., explosive destruction of an electrical power supply. The disadvantage of this approach is that it protects against only those events occurring in interior facilities, and accidental disruption of the ventilation flow could interrupt operation of the facility. Also, a security force might still be needed to protect this system.

5.5.2 Hardware/Personnel Tradeoffs

In the security systems just described, the largest part of the security costs is in security personnel salaries. For a low level of protection, the estimated cost of maintaining one watchman per shift was $125,000 per year out of a total annualized security system cost of $175,000. For a very high level of protection, the estimated cost of maintaining 12 guards plus supervisors was $2.2 million out of a total annualized security system cost of $2.6 million.

Table 5-9 shows the disposition of the guards and watchmen for the various levels of security protection. The major guard/watchman functions are (1) random patrol, (2) entry control including random or total search of entering personnel, vehicles and packages, (3) random or total search of exiting vehicles for unauthorized waste cargo, (4) random search of exiting people, packages or vehicles for SNM, and (5) response to alarms and other indications of intrusion.

Hardware can be used to support all these functions. Patrol can be aided or replaced by CCTV, but someone must still be available, at least part time, to monitor the CCTV. CCTV can, however, reduce the manpower required for the patrol function. It also potentially improves surveillance (since a monitor can quickly be switched from one part of the facility to another) and eliminates the vulnerability of the guard or watchman.

Entry and exit control can be performed with the aid of hardware (e.g., CCTV to a central station with remote control of the lock) or by the hardware alone (e.g., a card-key type system). One problem of a card-key type system is that anyone who obtains a key can gain access. Another problem is that the other entry/exit functions of search must be performed. While a combination card-key and portal detection system might be devised which would eliminate the need for guards or watchmen at personnel

Table 5-9. Disposition of Guards and Watchmen.

Low Level of Protection (Moderate for Theft/Sabotage Protection)

Requirement - 2 Watchmen per shift

Disposition - 1 on Random Patrol, Response to Alarms
1 Checking Exiting Vehicles for Waste Cargo

Moderate Level of Prctection

Requirement - 3 Watchmen per shift

Disposition - 2 at Main Gate (Random Searches Incoming Packages, etc.; Check of Exit Vehicles)
1 on Random Patrol

High Level of Protection

Requirement - 5 Guards and Supervisors

Disposition - 2 at Main Gate
1 and Supervisor at CAS
2 on Patrol and Train Gate Control

Very High Level of Protection

Requirement - 12 Guards and Supervisors

Disposition - 7 Reserve Force and Patrol
2 Main Gatehouse
2 Train Gatehouse
1 and Supervisor at CAS

entry/exit points, someone would still have to be available to respond to alarms, to inspect exiting vehicles, and to inspect incoming and outgoing packages. It appears doubtful that entry control apparatus can replace guards or watchmen at a high-level waste repository.

Response to alarms, including use of force if intrusion is confirmed, also has some hardware possibilities. It is possible to construct traps (e.g., automatically closing and locking doors) or chemical dispensers (e.g., foam, tear gas, smoke), especially in interior areas. Also, guard dogs could be released, especially in exterior (cask parking) areas. These responses might be triggered automatically by the alarm system or might be released by a guard or watchman at a central alarm station, who might also have CCTV surveillance.

The advantage of such response apparatus is the potential elimination of the need to maintain a response force (about $160,000 per man-year cost savings). The major disadvantage is the hazard of possible accidental or mistaken deployment against legitimate repository employees or visitors. The effects of this hazard, however, might be reduced by using methods which cause minimum damage to the individual(s) affected.

6. MATERIAL CONTROL AND ACCOUNTING REQUIREMENTS

6.1 GENERAL

Material control and accounting (MC&A) measures are important parts of both domestic and international safeguards systems. For domestic safeguards, MC&A measures complement physical protection measures, and for international safeguards, MC&A measures complement containment and surveillance measures. In both domestic and international safeguards, the key role of MC&A is timely detection of SNM losses which are larger than specified amounts.

For domestic safeguards, the highest-consequence malevolent act of concern is the detonation of a nuclear explosive device in a highly populated area. The resulting extremely high loss of life, which can significantly exceed even that resulting from reactor core meltdown with breach of containment, argues for an extremely high level of protection against theft of SNM which can be readily converted into weapon-usable material. The issue of how the level of protection should vary for different forms of SNM, whose conversion to weapon-usable material ranges from very easy to very difficult, depends on whether the subnational or national adversary is being considered. Both types of adversary can credibly misuse SNM which is easily converted to weapon-usable material. However, as the difficulty of conversion increases, the subnational adversary becomes less credible. For example, conversion of LEU by either enrichment or by reactor irradiation and subsequent reprocessing to extract Pu is generally considered to be incredible for subnational adversaries. This view is reflected by NRC's rules which until this year did not require physical protection for unirradiated LEU. The new rule (10CFR Part 73.67), which became effective March 25, 1980, requires only a low-level of protection for 10 kg or larger quantities of LEU (<10% enriched in U-235).

In contrast, international safeguards are concerned with detecting the efforts of a nation, whose resources can include reactors and reprocessing facilities, to produce a nuclear weapon. Hence, all forms of SNM, including unirradiated LEU, which could be converted to weapon-usable material, would need to be protected. The SNM could be acquired by diversion from the nation's own nuclear fuel cycle or by theft from that of another nation. Two 1967 studies, the Lumb Panel Report[47] and the Strategic Importance Study,[48] recommended that international safeguards concerns be included in the U.S. safeguards program. Since the 1960s, U.S. MC&A requirements have reflected international safeguards concerns for LEU as well as for HEU and other SSNM. Today, the MC&A requirements of 10CFR Part 70 for LEU and HEU are very similar. The main differences are associated with MC&A program change notices, Part 70.32(c); inventory frequency, Part 70.51(e); LEMUF limits, Part 70.51(e); and scrap control procedures, Part 70.58(i). Hence, it appears that international safeguards concerns provide the principal basis for NRC's general policy on MC&A requirements for SNM. This implied policy, to provide protection proportional to the ease of converting SNM to weapon-usable form, is used in the next section to consider candidate MC&A requirements for waste materials which could be stored in a HLW repository.

6.2 MC&A REQUIREMENTS FOR DIFFERENT WASTE TYPES

Six different waste types were identified in Chapter 3 as candidate materials to be emplaced in a HLW repository. The ease by which these different waste types can be converted into weapon-usable material is determined mainly by their SNM content and associated radiation level. Physical and chemical forms are of less importance. SNM content influences the complexity of the conversion process and determines how much waste material has to be processed to recover a weapon quantity of material. Radiation level determines the material handling requirements for the conversion process. These two key characteristics are given in Table 6-1 for each of the six waste types. The SNM contents were obtained from the data of Table 3-6 and from Reference 49. The radiation levels are from References 5 and 49. The key features of the data in Table 6-1 are:

Table 6-1. SNM Content and Radiation Level for Each Waste Type.

WASTE TYPE	APPROXIMATE SNM CONTENT PER WASTE CONTAINER		APPROXIMATE DOSE RATE AT SURFACE OF WASTE CONTAINER (REM/HR)
	Kg of Pu	Kg of LEU	
Spent Fuel			
- PWR	4.0	440	2×10^5
- BWR	1.5	180	10^5
HLW (w Pu)	30	18	10^5 to 10^6
HLW (w/o Pu)	.15	18	10^5 to 10^6
Cladding Hulls	.02	--	10^3
ILW-TRU	.005	--	.02 to 300
LLW-TRU	.008	--	< 0.2

- Spent fuel and HLW (w Pu) contain significant quantities of Pu which is recoverable.
- The other waste types contain small quantities of Pu which would be difficult to recover.
- Spent fuel contains significant quantities of LEU which is recoverable.
- HLW contains modest quantities of LEU which would be difficult to recover.
- The radiation levels of spent fuel and HLW are high enough to be lethal unless the material is shielded during handling.
- The radiation levels of LLW and some ILW are low enough to permit contact handling.

MC&A requirements for the above waste types were examined at Oak Ridge National Laboratory (ORNL) for DOE's Office of Waste Isolation and reported in May 1978.[50] The criteria used to establish requirements were that MC&A measures should provide appropriate and reasonable means for detecting and quantifying possible losses of materials. The ORNL study considered three levels of MC&A.

- Level 1 - Item control based on item identification and item accountability.
- Level 2 - Tamper indication to detect loss during shipment.
- Level 3 - Nondestructive assay (NDA) to verify the declared SNM content of waste containers.

The item identification would consist of permanent, unique, machine-readable markings inscribed in the surface of the waste container. Item accountability would include shipper-receiver comparisons and records on the locations of all waste containers. Containers which are sealed by welding are considered to have implicit tamper indication because leak tests, contamination wipes or visual inspection should be sufficient to detect breaches of container integrity. Tamper indication for waste containers which are not welded would be provided by use of conventional seals. Because conventional seals can be damaged accidently, backup tests such as weight measurements or radiation scans should be used when needed. The recommendations by the ORNL study on the MC&A measures which should be used for each waste type are summarized in Table 6-2. The results show that item identification, item accountability and some form of tamper indication, either implicit or explicit plus backup, should be used for each waste type. Also, the ORNL study concluded, based in part on a separate evaluation of non-destructive assay (NDA) for nuclear waste[51], that "quantitative assay should not be attempted or required."

The ORNL study identified LLW as the waste type which presents a serious potential problem from a MC&A point of view. The radiation level is low permitting contact handling, the points of origin can be many and varied, and the resulting waste materials can be many and varied. As a result there are greater possibilities that the wrong quantities of waste are put into the LLW containers, either accidentally or intentionally, than for the other waste types. The ORNL study argues that this potential problem is better addressed at the shipper facilities rather than at the repository.

Los Alamos Scientific Laboratory (LASL) completed a study for DOE's Office of Safeguards and Security in 1979 which included consideration of MC&A requirements for a HLW repository.[49] This study generally supported the recommendations of the ORNL study. However, three of the LASL recommendations differed from those of the ORNL study. First, the ORNL study did not mention explicit tamper indication for spent fuel (i.e., seals on spent-fuel casks during shipment) whereas the LASL study recommended it. Second, the ORNL study concluded that NDA should not be used for any waste types while the LASL study suggested that NDA may be needed for spent fuel or possibly for non-safeguards purposes associated with process control, health and safety, or criticality control. The LASL study suggested that NDA measurements by shippers and receivers "could be used to draw shipper-receiver balances and to provide direct verification of the fissile plutonium and uranium contents." However, it concluded that "it is presently infeasible to make direct, NDA measurements of the plutonium content of

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Table 6-2. Summary of 1978 ORNL Study and 1979 LASL Study Recommendations on MC&A Requirements for Each Waste Type

WASTE TYPE	ITEM IDENTIFICATION	ITEM ACCOUNTABILITY	TAMPER INDICATION			QUANTITATIVE ASSAY (NDA)
			IMPLICIT	EXPLICIT	BACKUP	
Spent Fuel	Yes	Yes	Yes	Yes(a)		No(b)
HLW (w Pu)(c)	Yes	Yes	Yes			No
HLW (w/o Pu)	Yes	Yes	Yes			No
Cladding Hulls	Yes	Yes	Yes			No
ILW-TRU	Yes	Yes		Yes	Yes	No
LLW-TRU	Yes	Yes		Yes	Yes	No

a. Only LASL study recommended explicit tamper indication for spent fuel.

b. LASL study indicated possible need for NDA of spent fuel.

c. LASL study did not consider HLW containing unseparated Pu.

spent fuel to the accuracy required for safeguards accounting purposes." Third, the LASL study did not consider high-level waste containing unseparated Pu as a candidate waste type. Except for these three differences, the LASL study supported the key ORNL study recommendations. In particular, the LASL study strongly supported the ORNL recommendation that MC&A for LLW be emphasized at shippers' facilities rather than at the repository. The LASL study also emphasized a broader range of international safeguards concerns. For example, criteria for the termination of safeguards were considered.

Examination of the ORNL study and LASL study recommendations summarized in Table 6-2 may give the impression that the MC&A requirements for LLW and ILW equal or possibly exceed those for spent fuel and HLW. This result appears to contradict the previously discussed general policy of providing protection proportional to the ease of converting the SNM to weapon-usable form. The apparent reason for this contradiction is an implicit assumption that material substitution strategies can work for LLW and ILW but cannot work for spent fuel and HLW. For LLW and ILW, it is assumed that more attractive forms of SNM may be introduced covertly into waste containers for later retrieval. The role of the recommended MC&A measures is to block this diversion or theft path. For spent fuel and HLW, it is implictly assumed that other radioactive material containing less Pu cannot be substituted for these waste types. Hence, the MC&A measures recommended for LLW and ILW are designed to counteract the smuggling of SNM which is more readily converted to weapon-usable form than LLW or ILW, whereas the MC&A measures recommended for spent fuel and HLW are intended to protect against diversion or theft of these materials. Spent fuel and HLW also have the self protection provided by lethal levels of radiation.

Finally, it is noted that some form of NDA may serve two functions not addressed by other MC&A measures. First, if material substitution strategies were to become accepted for spent fuel, NDA may be useful as a countermeasure. Second, if anomalies were to arise during international safeguards inspections, NDA may be useful for resolving them.

spent fuel to the accuracy required for safeguards accounting purposes." Third, the LASL study did not consider high-level waste containing unseparated Pu as a candidate waste type. Except for these three differences, the LASL study supported the key ORNL study recommendations. In particular, the LASL study strongly supported the ORNL recommendation that MC&A for LLW be emphasized at shippers' facilities rather than at the repository. The LASL study also emphasized a broader range of international safeguards concerns. For example, criteria for the termination of safeguards were considered.

Examination of the ORNL study and LASL study recommendations summarized in Table 5.2 may give the impression that the MC&A requirements for LLW and ILW equal or possibly exceed those for spent fuel and HLW. This result appears to contradict the previously stated general policy of providing protection proportional to the ease of converting the SNM to weapons-usable form. The apparent reason for this contradiction is an implicit assumption that material substitution strategies can work for LLW and ILW but cannot work for spent fuel and HLW. For LLW and ILW, it is assumed that more attractive forms of SNM may be introduced covertly into waste containers for later retrieval. The role of the recommended MC&A measures is to discourage diversion attempts for spent fuel and HLW. It is implicitly assumed that since radioactive material containing less Pu cannot be substituted for these waste types. Thus, the MC&A measures recommended for LLW and ILW are designed to counteract the smuggling of SNM which is more readily converted to weapons-usable form than LLW or ILW, whereas the MC&A measures recommended for spent fuel and HLW are intended to protect against diversion or theft of these materials. Spent fuel and HLW also have the self protection provided by lethal levels of radiation.

Finally, it is noted that some form of NDA may serve two functions not addressed by other MC&A measures. First, if material substitution strategies were to become accepted for spent fuel, NDA may be useful as a countermeasure. Second, if anomalies were to arise during international safeguards inspections, NDA may be useful for resolving them.

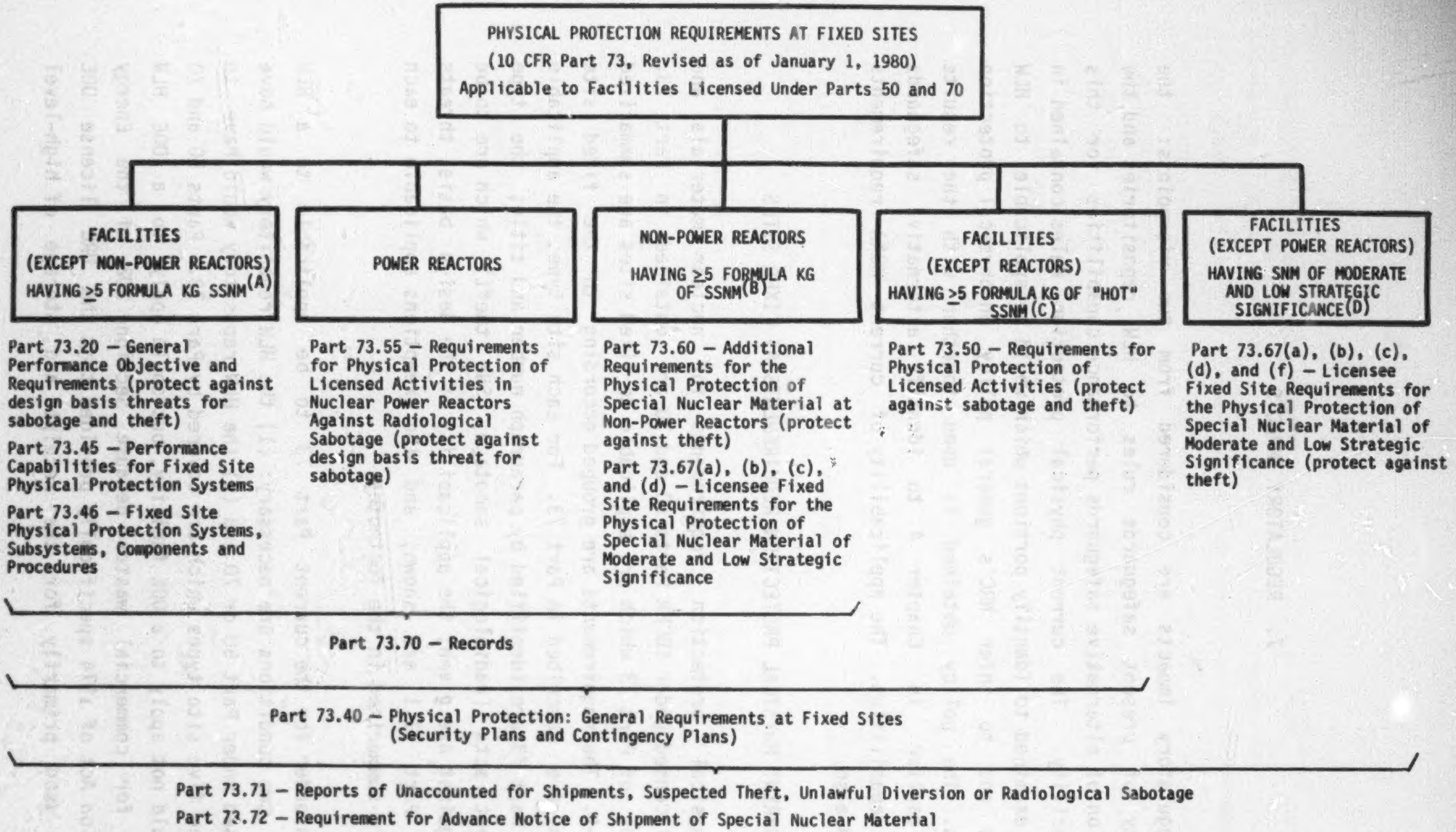
7. REGULATORY IMPACTS

Regulatory impacts are considered from two viewpoints: the applicability of present safeguards rules to HLW repositories and the identification of alternative safeguards performance capabilities for this type of facility. The current physical protection rules contained in 10CFR73 are examined to identify portions which would be applicable to HLW repositories and to infer NRC's general policy on physical protection requirements. The policy obtained is used together with the results presented earlier in Chapter 4 to identify alternative safeguards performance capabilities. The applicability of current MC&A requirements is reviewed also.

7.1 CURRENT PHYSICAL PROTECTION REQUIREMENTS AT FIXED SITES

Physical protection requirements for nuclear materials and facilities licensed under 10CFR Parts 50 and 70 are contained in Part 73. The portions of Part 73 which are applicable to fixed sites are summarized in Figure 7-1. The requirements are grouped according to the fixed site types which are described in Part 73. For each site type, the applicable portions of Part 73 are identified by paragraph number and title; the type of malevolent acts (radiological sabotage, SNM theft) which are to be protected against are given; the applicability of the design basis threats defined in Part 73.1 are shown; and the exemptions applicable to each paragraph are summarized in the footnotes.

In order for the current Part 73 to be applicable to a HLW repository, two conditions are necessary: (1) the HLW repository would have to be licensed under Part 50 or 70 and (2) the HLW repository would have to be one of the five site types which are covered by Part 73. Parts 50 and 70 normally would not apply to a DOE facility, but could apply to a DOE HLW repository for commercial wastes because Section 202 of the Energy Reorganization Act of 1974 specifically provides that the NRC license DOE "Facilities used primarily for the receipt and storage of high-level


PHYSICAL PROTECTION REQUIREMENTS AT FIXED SITES
(10 CFR Part 73, Revised as of January 1, 1980)
Applicable to Facilities Licensed Under Parts 50 and 70
FACILITIES (EXCEPT NON-POWER REACTORS) HAVING ≥5 FORMULA KG SSNM(A)
POWER REACTORS
NON-POWER REACTORS HAVING ≥5 FORMULA KG OF SSNM(B)
FACILITIES (EXCEPT REACTORS) HAVING ≥5 FORMULA KG OF "HOT" SSNM(C)
FACILITIES (EXCEPT POWER REACTORS) HAVING SNM OF MODERATE AND LOW STRATEGIC SIGNIFICANCE(D)
Part 73.20 — General Performance Objective and Requirements (protect against design basis threats for sabotage and theft)
Part 73.45 — Performance Capabilities for Fixed Site Physical Protection Systems
Part 73.46 — Fixed Site Physical Protection Systems, Subsystems, Components and Procedures
Part 73.55 — Requirements for Physical Protection of Licensed Activities in Nuclear Power Reactors Against Radiological Sabotage (protect against design basis threat for sabotage)
Part 73.60 — Additional Requirements for the Physical Protection of Special Nuclear Material at Non-Power Reactors (protect against theft)
Part 73.67(a), (b), (c), and (d) — Licensee Fixed Site Requirements for the Physical Protection of Special Nuclear Material of Moderate and Low Strategic Significance
Part 73.50 — Requirements for Physical Protection of Licensed Activities (protect against sabotage and theft)
Part 73.67(a), (b), (c), (d), and (f) — Licensee Fixed Site Requirements for the Physical Protection of Special Nuclear Material of Moderate and Low Strategic Significance (protect against theft)
Part 73.70 — Records
Part 73.40 — Physical Protection: General Requirements at Fixed Sites (Security Plans and Contingency Plans)
Part 73.71 — Reports of Unaccounted for Shipments, Suspected Theft, Unlawful Diversion or Radiological Sabotage
Part 73.72 — Requirement for Advance Notice of Shipment of Special Nuclear Material

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(A) EXEMPTIONS: U (<20% U-235), Hot SNM, SNM laboratory samples (<350 g), SNM at non-power reactors.

(B) EXEMPTION: Hot SNM.

(C) "Hot" SSNM is SSNM which is not readily separable from other radioactive material and which has a total external radiation dose rate in excess of 100 rems per hour at a distance of 3 feet from any accessible surface without intervening shielding.

(D) EXEMPTIONS: Hot SNM, sealed Pu-Be neutron sources (<500 g Pu), plutonium (>80% Pu-238).

Figure 7-1. Protection requirements at fixed sites

radioactive wastes resulting from activities licensed under such Act." The current Part 50, which applies to production facilities (production reactors, enrichment plants, fuel reprocessing plants) and utilization facilities (power reactors, research reactors, test reactors and other non-production reactors), would not apply to a HLW repository. The MC&A requirements of the current Part 70, which applies to the possession and use of SNM, may not apply because HLW repository activities do not involve "use" of SNM. If Part 70 MC&A requirements were to be applicable, all parts which are applicable only when the quantity of SNM exceeds one effective kilogram (e.g., Parts 70.57 and 70.58), would be exempted because the HLW repository is a "waste disposal operation." Part 70.51(c), which deals with material control and accounting procedures, is not subject to this exemption.

The site type to which a HLW repository could correspond is "Facilities (except Reactors) Having $\geq$5 Formula Kg of Hot SSNM." Spent fuel, which DOE is currently planning to put in its HLW repository, qualifies as "hot" SSNM. Other waste types containing Pu may also qualify. The level of protection required by Part 73.50 for hot SSNM is higher than that found in Chapter 4 to be appropriate for spent fuel, but equivalent to or lower than that found to be appropriate for some other HLW types. It is observed that prior to March 25, 1980, the requirements of Part 73.50 were applicable to the first site type (i.e., facilities having five or more formula kilograms of SSNM). "Facilities (except Reactors) Having $\geq$5 Formula Kg of Hot SSNM", to which Part 73.50 now applies, would include facilities for storage of spent fuel away from reactors.

Because of the questions raised regarding the applicability of Part 70 to HLW repositories and regarding the appropriateness of the level of protection required by Part 73.50, it would be prudent to plan for some modification of the rules to accommodate the safeguards licensing of HLW repositories.

7.2 NRC'S GENERAL SAFEGUARDS POLICY

Examination of Part 73 to identify a high-level safeguards objective yields the following statement:

> Protection against degradation of "the common defense and security of the United States" and against "unreasonable risk to the public health and safety."

Most attention seems to be focused on the second part. This is indicated by the May 1976 NRC safeguards objective[52] to achieve "a level of protection against such acts to insure against significant increase in the overall risk of death, injury, or property damage to the public from other causes beyond the control of the individual." Both statements use "risk to the public" as the key measure. The concept of risk normally implies the product of two terms, frequency x consequences, which may be summed over multiple events. The first term, the frequency of occurrence of radiological sabotage or SNM theft, is difficult to predict. However, up to now in the United States, the frequency has been very low for all such malevolent acts which produce significant public health consequences, such as fatalities. Because the frequency has been very low, and recognizing that its magnitude in the future is uncertain, attention has been focused on the second term, consequences. As a result, NRC's general safeguards policy appears to be to require protection to be proportional to the potential public health consequences of malevolent acts involving radiological sabotage and SNM theft. However, as discussed earlier in Section 6.1, NRC policy on SNM theft appears to also include consideration of the difficulty for an adversary to cause certain consequences, i.e., to produce and detonate a nuclear explosive device. Specifically, the above general safeguards policy would be directly applicable to protection of SNM which can be readily converted to weapon-usable material, but for other forms of SNM, protection against theft would be proportional to the ease of converting the SNM to weapon-usable form. Inclusion of the difficulty of causing consequences can be interpreted as recognition of its influence on the first term of the risk equation, frequency of occurrence.

The above qualitative statement of general safeguards policy is supported by the trend in the quantitative data presented in Chapter 4 on the level of protection vs level of consequences relationship which seems to be implicit in the current rules. This interpretation of NRC's general safeguards policy was used in Chapter 4 to obtain the safeguards requirements for protection of different waste types at the remote and rural repository site locations. The policy interpretation is also used in the next section to examine alternatives for safeguards performance capabilities.

7.3 SAFEGUARDS PERFORMANCE CAPABILITY ALTERNATIVES

In this section, alternatives for safeguards performance capabilities at HLW repositories are formulated. First, the logical steps that are used in such a formulation are described, and two examples of safeguards performance capabilities, 10CFR Parts 73.45 and 73.67, are compared in order to illustrate key points in the discussion. As pointed out in Chapter 4, the safeguards problem at HLW repositories depends on the the waste type and the site location. The storage of spent-fuel waste at either a rural or remote site is used as a basis of discussion.

A flow chart showing the steps used to formulate safeguards capabilities and systems is shown in Figure 7-2. The process starts with a statement of the safeguards concerns because these are the reasons for protecting nuclear materials and facilities. The concern of radiological sabotage is outlined because it is the primary safeguards concern at HLW repositories. The second step is to determine the range of consequences that could result if one of the concerns became a reality. Consequence results for HLW repositories have been calculated and presented in Chapter 4. The consequence results are input to the third step which is to use NRC's general safeguards policy to determine the appropriate level of protection required by the level of potential consequences. This step was discussed in Section 7.2. The fourth step is to formulate alternative performance capabilities that will give this level of protection. A preferred capability is then selected. This forms the basis for the fifth step, the conceptual design of technical alternatives for the physical

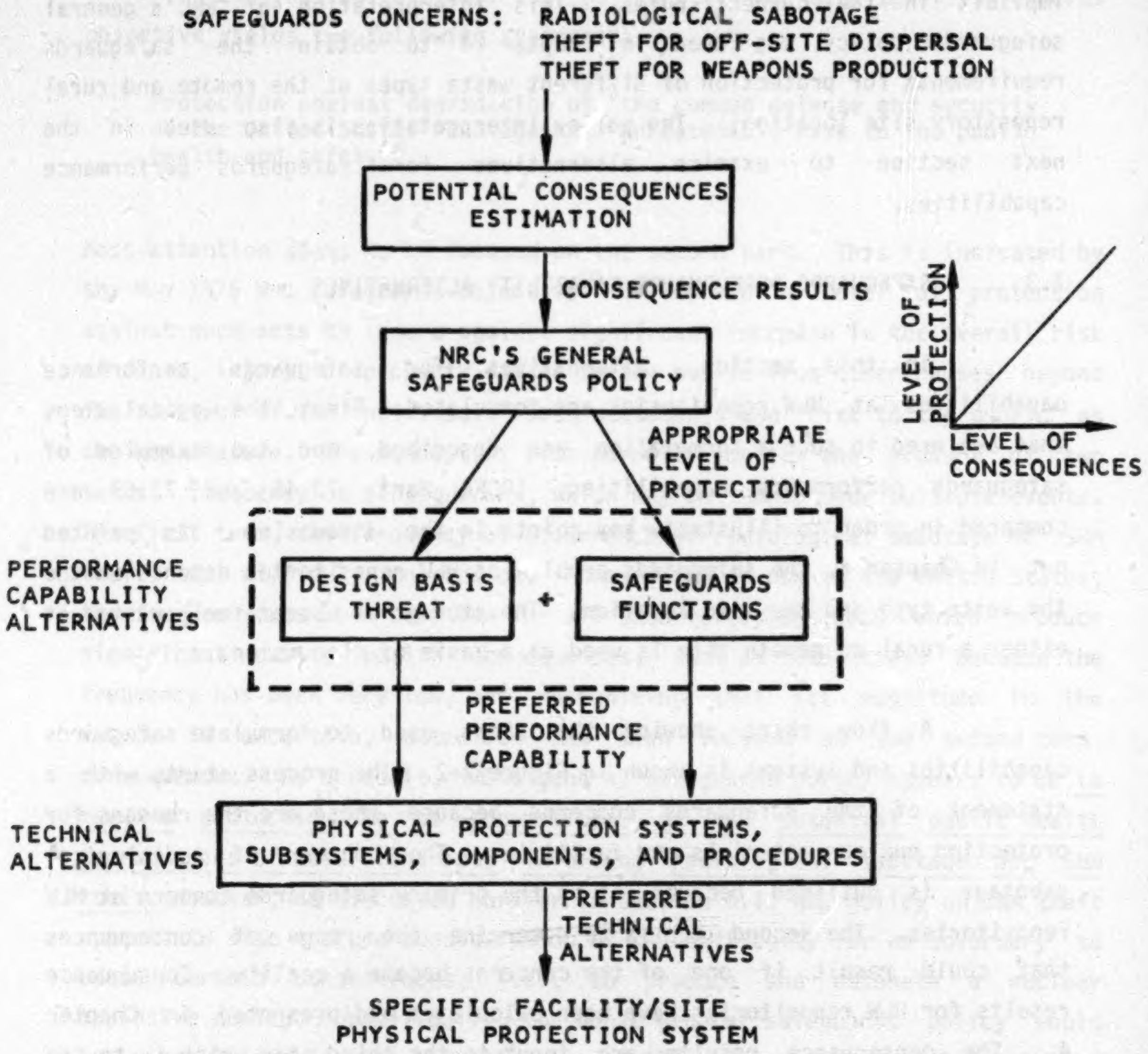
SAFEGUARDS CONCERNS:
RADIOLOGICAL SABOTAGE
THEFT FOR OFF-SITE DISPERSAL
THEFT FOR WEAPONS PRODUCTION
POTENTIAL CONSEQUENCES ESTIMATION
CONSEQUENCE RESULTS
NRC'S GENERAL SAFEGUARDS POLICY
LEVEL OF PROTECTION
LEVEL OF CONSEQUENCES
APPROPRIATE LEVEL OF PROTECTION
PERFORMANCE CAPABILITY ALTERNATIVES
DESIGN BASIS THREAT
+
SAFEGUARDS FUNCTIONS
PREFERRED PERFORMANCE CAPABILITY
TECHNICAL ALTERNATIVES
PHYSICAL PROTECTION SYSTEMS, SUBSYSTEMS, COMPONENTS, AND PROCEDURES
PREFERRED TECHNICAL ALTERNATIVES
SPECIFIC FACILITY/SITE PHYSICAL PROTECTION SYSTEM

Figure 7-2. Flow Chart Showing Steps Used to Formulate Physical Protection Capabilities and Systems.

protection systems.' Given a conceptual design, a specific physical protection system can be designed for each facility and site.

The process can be modified by retaining more than one of the performance capabilities formulated in step four and considering technical alternatives for each before selecting the preferred capability.

The purpose of this section is to perform step four and formulate a few performance capabilities for physical protection of HLW repositories. It is important to remember that the purpose for the statement of performance capabilities is to provide a sufficient basis for design of a physical protection system. Therefore, as indicated on Figure 7-2, a statement of performance capability consists of two parts: the design basis threat the system must protect against and the safeguards functions the system must perform to provide this protection. Thus, alternative performance capabilities can be formulated by selecting combinations of design basis threat and safeguards functions which provide the desired level of protection.

In order to illustrate some of the key points in the process of formulating performance capabilities, two statements of performance capabilities given in Part 73 can be used: (1) Part 73.45 for facilities having five or more formula kilograms of SSNM; and (2) Part 73.67 for facilities having special nuclear material of moderate and low strategic significance. The facilities licensed under Part 73.45 require an extremely high level of protection while those licensed under Part 73.67 require a low to moderate level based on the potential consequences (see Chapter 4).

Table 7-1 gives a summary of the statements of the performance objectives and design basis threats, and safeguards functions found in these parts of the regulations. The important words and phrases have been underlined. The first underlined phrases in each of the two performance objectives state NRC's general safeguards policy, i.e., protect in a way that is consistent with consequences or, in other words, protect so that the risk of harm to the public is reasonable. Thus, the two protection systems have the same objective but because the potential consequences differ

Table 7-1. Comparison of Safeguards Performance Objectives and Functions for Different Levels of Protection

	10CFR73.45	10CFR73.67	
	REPROCESSING AND FACILITIES WITH >5 FORMULA KG SSNM	MODERATE SSNM	LOW SSNM
Performance Objectives (including design basis threat)	Establish and maintain physical protection system to provide high assurance that activities involving SNM are not inimical to the Common Defense and Security and do not constitute an unreasonable risk to public health and safety. The system shall be designed to protect against a design basis threat of: 1) Sabotage by a determined violent external assault attack by stealth, or deceptive actions, of several persons who are well-trained, have an insider accomplice, suitable weapons, and other necessary equipment; and an insider including an employee in any position; and (2) theft by a determined external assault, attack by stealth or deceptive actions, by a small group having the characteristics given in (1) plus have the ability to operate in two or more teams; and a conspiracy between insiders in any position.	Establish and maintain a physical protection system to minimize the possibilities for unauthorized removal of SNM consistent with the potential consequences and facilitate the location and recovery of missing SNM. The system shall provide early detection of and response to attempts at unauthorized access, unauthorized activities, and unauthorized SNM removal by an external adversary.	
Safeguards Functions	- Detect and assess unauthorized access into PAs, MAAs or VAs - Detect and assess unauthorized activities within PAs, MAAs, or VAs - Permit authorized placement and movement of SNM within MAAs - Detect unauthorized removals of SNM from MAAs - Confirm identity and quantity of SNM removal from MAAs - Respond to all alarms and engage adversary to impede until off-site forces arrive	- Detect and assess unauthorized access into CAAs having SNM - Detect and assess unauthorized activities by an external adversary within CAAs having SNM - Assure proper placement and custody of SNM - Detect removal of SNM from CAA - (Same capability implied but not stated) - Respond to indications of unauthorized removals of SNM and notify appropriate (other) response forces in order to facilitate recovery of SNM.	

greatly, the corresponding performance capabilities will be different. This is first seen in the statement of the design basis threat which for theft is an external assault by a small group of outsiders aided by one insider or a conspiracy between insiders for Part 73.45, but only an external adversary for Part 73.67.

There are six safeguards functions listed for each case and they are nearly identical except for the last capability, that of response. Part 73.45 safeguards must respond to engage the adversaries to impede them until off-site forces arrive, but Part 73.67 safeguards must only notify appropriate response forces in order to facilitate a recovery of the stolen SNM. While both safeguards have similar functions to detect and assess unauthorized access, activities, placement of SNM, and removal of SNM, the fact that the design basis threat for Part 73.45 has so many more resources than that for Part 73.67 means that the safeguards systems which perform these functions will differ.

In order to formulate performance capabilities for HLW repositories, the differences in consequences for the different waste types and site locations must first be considered. Thus, based on the results presented in Chapters 3 and 4, a rural site storing calcined HLW with plutonium demands a very high level of protection. A rural or remote site storing spent-fuel demands only a low-level of protection. The remainder of this discussion will focus on formulation of the performance capability alternatives to give this low level of protection for spent-fuel waste repositories.

The previous discussion of Parts 73.45 and 73.67 points to a maximum capability in responding to theft (of preventing the adversaries from succeeding) and to a minimum capability of alerting off-site response forces (so that recovery of the stolen SNM is facilitated), respectively. The analogous extremes for sabotage would be a prevention capability as the maximum and a capability to notify appropriate emergency response teams so that they can mitigate the consequences of an on-site dispersal as the minimum. There are a number of ways the response teams could do this:

(1) Take actions to reduce the fraction of dispersed radioactivity released from the site. These actions would probably be initiated on-site and might include shut-down of the ventilation system and use of a spray system to deposit the radioactivity on the site.

(2) Take actions to reduce the transport of the radioactivity to a population zone. This is an area that merits examination because the response is such as to allow this to be action by an off-site emergency team. It does imply a need for good monitoring systems around the site to detect the direction and intensity of the released radioactivity.

(3) Take actions to reduce the amount of radioactivity that gets into pathways that lead to man. For example, if certan food chains cause the most consequences by ingestion, then take steps to eliminate some link in this chain in the contaminated area. Note that consequences by ingestion are not included in the consequences given in this report and thus credit for these actions is already taken.

(4) Take actions to reduce the fraction of uptake to man. This includes wearing gas masks or filters to prevent inhalation and not consuming foods from the contaminated area.

Capabilities to perform functions 2 through 4 above are independent of the design basis threat level and are capabilities probably best handled by government organizations. If these capabilities existed, a logical physical protection requirement would be to detect, assess and respond to sabotage in a timely way so that these government organizations could mitigate the consequences. However, even if this capability is possible, it is not clear that there are any places where it exists. It is, therefore concluded that the performance capability alternatives consist of

(1) Detecting, assessing and responding to the design basis threat to prevent an on-site dispersal;

(2) Detecting, assessing and responding to the design basis threat to impede the adversary from a on-site dispersal until notified, off-site forces respond;

(3) Detecting, assessing and responding to the design basis threat to prevent a significant off-site release if there is an on-site dispersal;

(4) Detecting, assessing and responding to the design basis threat to impede the adversary from an on-site dispersal long enough so that when notified, off-site emergency teams can respond to take actions to prevent a significant off-site release.

The decision about the preferred alternative will be based on a number of criteria. The first and foremost is feasibility and the second is cost/benefit. The reasons are as follows. First, for sabotage the times from the start of unauthorized access to completion of dispersal are on the order of a few to tens of minutes. Thus, for an off-site force to be useful in preventing dispersal, the on-site security force must be capable of delaying the adversary. Second, once the material is released off-site, there are no clear or proven methods for response. Thus, the first question is whether there are technical ways to implement a capability requirement reducing off-site releases if there is an on-site release. The second question is whether these ways are cost effective compared to on-site guards that can delay an adversary until assistance arrives.

7.4 MATERIAL CONTROL AND ACCOUNTING REQUIREMENTS

The material control and accounting requirements contained in 10CFR70 have been summarized in Table 7-2. This summary is organized according to the quantity of SNM whose possession and use would require different paragraphs of Part 70 to be applicable. The quantity of SNM which causes the various paragraphs of Part 70 to be applicable is the total quantity of SNM located at a facility and is independent of the concentration of SNM. The important exemptions and the requirements variations, which depend for SNM type and quantity, are included in the footnotes to the table. As mentioned earlier in this chapter, the applicability of Part 70 is uncertain because SNM is not "used," at least in any conventional sense, in a HLW repository. If Part 70 were found to be applicable to HLW repositories, either by interpretation or by modification, the applicable paragraphs would be all of those applicable to any quantities of SNM, those applicable to quantities of SNM exceeding 1 g and 350 g, and Part 70.51(c). The remainder of Part 70 would be exempted because the SNM is involved in a "waste disposal operation."

Table 7-2. Applicability of 10 CFR Part 70 Paragraphs According to Quantity of SNM.

10 CFR PART 70 PARAGRAPH		QUANTITY OF SNM
NUMBER	SUBJECT	
70.21 - 70.23	License Applications	Any
70.31 - 70.37	Licenses to Use and Possess SNM	↓
70.41 - 70.44	SNM Acquisition, Use, Transfer; Creditors' Rights	↓
70.51(b)	Records	↓
70.52(a)	Accidental Criticality & SNM Loss Reports	↓
70.55	Inspections	↓
70.56	Tests	↓
70.59	Effluent Monitoring Reports	↓
70.61 - 70.62	License Modification and Revocation	↓
70.52(b)	SNM Theft or Theft Attempt Reports	≥1 g
70.54	Nuclear Material Transfer Reports (Form NRC-742)	≥1 g
70.51(d)	Annual Inventory	>350 g
70.53(a)	Material Status Report (Form NRC-741)	>350 g
70.22(b)	MC&A Plan in License Application	>1 eff. kg (A)
70.32(c)	MC&A Plan Change Notice	↓ (A,B)
70.51(c)	MC&A Procedures	↓
70.51(e) - (h)	Material Balance, Inventory and Records	↓ (A,C,D)
70.53(b)	Excess MUF and LEMUF Reports	↓ (A,C)
70.57	Measurement Control Program	↓ (A)
70.58	Fundamental Nuclear Material Controls	↓ (A,E)

(A) EXEMPTIONS: SNM uses involved in reactor operation or waste disposal operation, and SNM in sealed sources.

(B) MC&A program changes which do not reduce its effectiveness are to be reported in writing to NRC within 2 months for SSNM, except Pu (≥80% Pu-238), and within 6 months for LEU and Pu (≥80% Pu-238).

(C) EXEMPTION: Irradiated fuel involved in research, development and evaluation at facilities other than fuel reprocessing plants.

(D) 1. Physical inventories are to be performed at least every 2 months for SSNM, except Pu (≥80% Pu-238) and HEU in shielded front end of fuel reprocessing plants, and at least every 6 months for LEU and the above Pu and HEU exceptions.

2. LEMUF for Pu or U-233 is not to exceed 200 g or 1% of additions or removals for fuel reprocessing plant or 0.5% for other facilities; LEMUF for HEU is not to exceed 300 g of U-235 or 0.7% of additions or removals for fuel reprocessing plant or 0.5% for other facilities; LEMUF for LEU is not to exceed 9,000 g of U-235 or 0.7% of additions or removals for fuel reprocessing plant or 0.5% for other facilities.

(E) Scrap assayed with measurement uncertainty exceeding 10% is to be processed and recovered within 6 months for SSNM, except Pu (≥80% Pu-238), and within 12 months for LEU and Pu (≥80% Pu-238).

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ACRONYMS

AFR - Away from reactor (spent fuel storage)
AMD - Aerodynamic median diameter
BWR - Boiling water reactor
CAA - Controlled access area
CAS - Central alarm station
CCTV - Closed circuit television
CFR - Code of federal regulations
CH - Contact handled (waste)
DEIS - Draft environmental impact statement
EIS - Environmental impact statement
GEIS - Generic environmental impact statement
HEPA - High-efficiency particulate air (filter)
HEU - Highly enriched uranium
HLW - High level waste
IAEA - International Atomic Energy Agency
ID - Identification
ILW - Intermediate level waste
LCF - Late cancer fatality
LEMUF - Low enriched materials unaccounted for
LEU - Low enriched uranium
LLEA - Local law enforcement agencies
LLW - Low level waste
M&M - Men and materials (access shaft)
MMD - Mass median diameter
MTHM - Metric ton heavy metal
NDA - Nondestructive assay
NRC - U.S. Nuclear Regulatory Commission
NYC - New York City
O&M - Operating and maintenance (costs)
ORNL - Oak Ridge National Laboratory
OWI - Office of Waste Isolation

PA - Protected area
PBQD - Parsons, Brinkerhof, Quade and Douglas
PNL - (Battelle) Pacific Northwest Laboratories
PSAR - Preliminary Safety Analysis Report
PWR - Pressurized water reactor
RH - Remoted handled (waste)
SAS - Secondary alarm station
SF - Spent fuel
SNM - Special nuclear material
SQ - Significant quantity
TRU - Transuranic
VA - Vital area
WIPP - Waste Isolation Pilot Plant

APPENDIX A

COMPUTER CODES USED IN CONSEQUENCE ANALYSIS

In the reference events considered in this study, the transport paths for radioactive aerosols are typically combinations of chambers and ventilation ducts. Thus, the transport model used in the work is a two-part model; the first part describes aerosol behavior in chambers while the second part describes aerosol behavior in pipes and ducts. The two parts of the model exist as computer codes which are discussed separately below.

A.1 THE HAARM-2 CODE

Aerosol behavior within chambers has been extensively studied in the past in relation to safety analyses of nuclear reactor designs. Mathematical models describing the behavior of aerosols in closed environments are well developed and have been verified with experimental comparisons. The models account for various mechanisms of agglomeration of airborne particulate matter as well as several processes of particle removal from closed systems. Assumptions common to all models are a well-mixed volume in which there are no spatial variations.

Several computer codes have been formulated from these mathematical aerosol behavior models. The HAA series developed by Atomics International[(1)] is one of these. The HAARM series of computer codes developed at Battelle-Columbus[(2)]. is essentially a revised version of the HAA series of codes. Both the HAARM-2 code and later versions of the HAA series (HAA-3 and HAA-3B) assume a log-normal particle size distribution characterized by a mean size and standard deviation. The HAARM-2 computer code used to study aerosol behavior in chambers in this work has been well documented[(2)] so only a brief describption will be given here. It is an updated and revised version of HAA-3B.

The integro-differential equation which describes aerosol bahavior is replaced with a set of first-order differential equations by assuming the time dependent particle number distribution to be log-normal. A set of simultaneous differential equations is obtained by analytic integration of the appropriate moments of the integro-differential equation and then solved numerically. This mathematical model will allow any combination of Brownian agglomeration, graviataional agglomeration, settling, wall plating (diffusion), leakage, and log-normal source (constant source rate). Turbulent agglomeration is not included because previous estimates of the importance of turbulent agglomeration indicate that the rates are usually much smaller than other agglomeration rates.(3,4)

The mathematical model on which the HAARM-2 code is based also allows temporal variation of chamber gas temprature, pressure and temperature normal to the chamber walls. Additionally, settling velocities which are dependent upon the morphological properties of individual agglomerates are corrected using a recent experimentally derived dynamic shape factor.

Input requirements for the code include specification of the particle source rate and its initial size distribution parameters, the chamber physical source rate and its initial size distribution parameters, the chamber physical conditions and atmospheric properties, and the volumetric leakage rate from the chamber. Among the useful quantities which the HAARM-2 code computers regarding the time-dependent behavior of the aerosol source are:

1. Suspended mass and number concentrations;
2. Settled, plated, and leaked masses;
3. Number median, mass median, and aerodynamic radii of suspended particles;
4. Removal halftimes for suspended, settled, and plated fractions.

A.2 THE DUCT CODE

A portion of an aerosol source released in a chamber can eventually be leaked to the outdoor environment via the ventilation air ducts. This portion may be quite small if the ventilation system paticulate filters are intact, but whether this is the case or not, a significant fraction of the aerosol particles may deposit within the ducts, depending on the characteristics of the ducts and of the aerosol. The DUCT computer code calculates the deposition fraction of an aerosol entering a duct as a function of the duct dimensions, geometry, and orientaion, the flow conditions, and the aerosol properties. The DUCT code is based on various mathematical models which describe the flow of particles through pipes and conduits.

There are numerous deposition mechanisms by which a flowing particles may be removed from an air stream. The principal mechanisms included in the duct model are diffusion, gravitational settling, and inertial impaction. For particles smaller than about 0.1-1 μm, turbulent diffusion, gravitational settling, and impaction in bends are significant. Other deposition mechanisms such as those caused by the effects of thermophoresis (thermal diffusion) or of electrical charging were neglected in the duct model because evaluations indicated these would not be significant for the conditions expected in the present analyses. Particle agglomeration effects were also ignored, partly because of the complexity that that would introduce, and also because of the relatively low suspended particulate concentrations that were anticipated.

The duct model uses equations developed by Beal(5,6) to describe simultaneous deposition of particles by Brownian and turbulent difussion. Since gravitational settling was neglected in Beal's analysis, this model is valid only for vertical ducts. For horizontal ducts, the equations of Matsui, et al.(7) and Yoshioka(8), which treat gravitational settling in addition to turbulent diffusion, are used. Finally, the theoretical results of Cheng and Wang(9) and of Yeh(10,11) are applied in the duct model to define impaction efficiencies for use in defining inertial impaction in bends.

Using the above series of models, the DUCT computer code computes the aerosol deposition fractions in a series of duct segments of a ventilation system. The mass median diameter and standard deviation of an aerosol leaking from a chamber into the duct is identical to that of the suspended aerosol in the chamber as calculated by the HAARM-2 code. The DUCT code gives the transmitted aerosol mass fraction at the exit of the duct segments and characterizes the exiting aerosol by a new mass median diameter and standard deviation.

A.3 GRAPHICAL METHOD FOR ESTIMATING AEROSOL RELEASE FRACTIONS

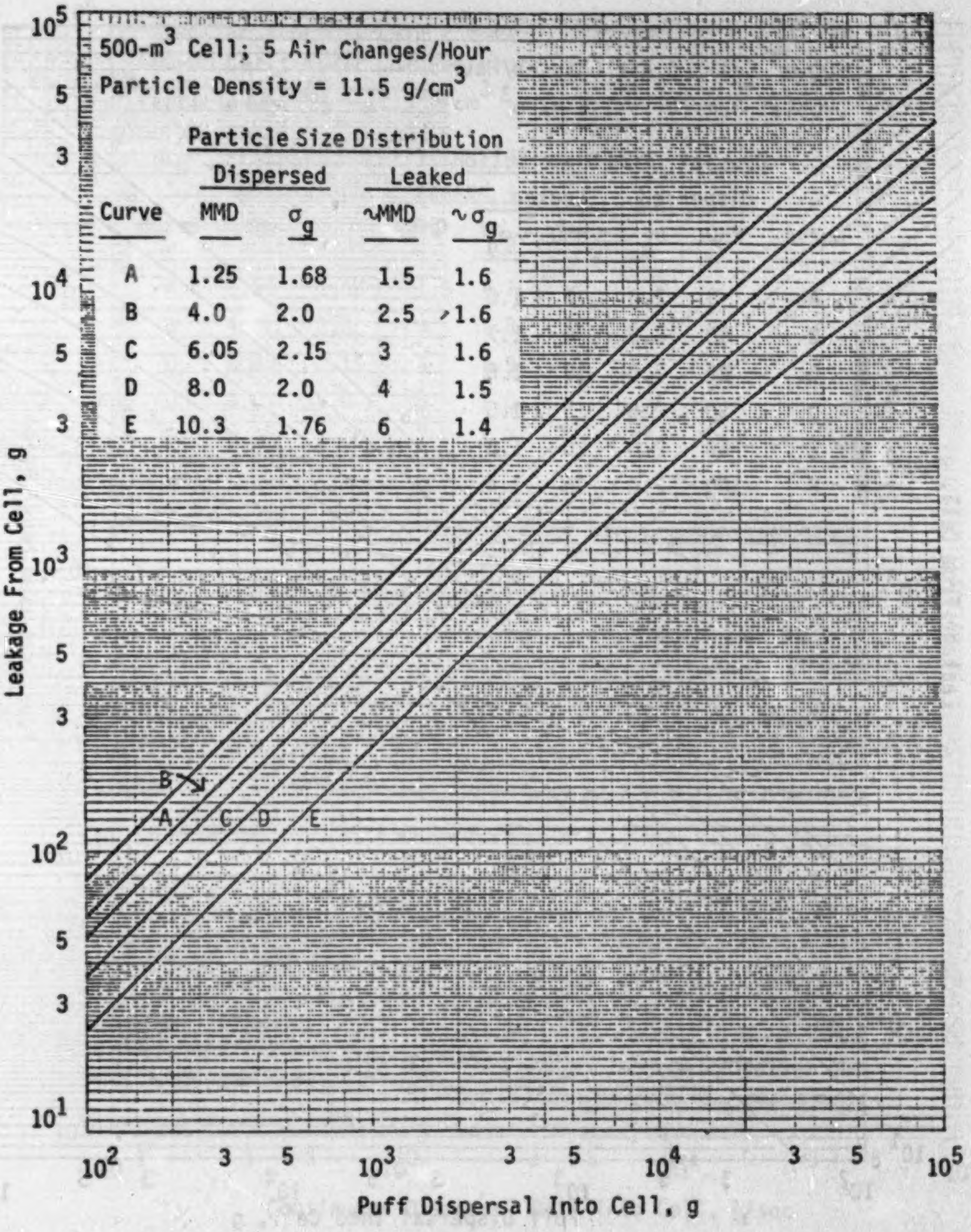
An informal, graphical method of estimating aerosol release fractions also was devised for use when formal computer calculations might be impractical. This method, which was developed from results of HAARM and DUCT calculations, is described below. It must be recognized as an approximate method, especially for estimating particles size distributions.

A large number of physical parameters must be specified to define an aerosol transport problem properly. These include cell dimensions and ventilation rate; duct dimensions and airspeed; properties of air; aerosol particle size distribution and source rate, etc. To enable development of a generalized method for estimating aerosol transport, the problem was reduced by fixing certain parameters at values typical of process cells and ventilation systems found in nuclear fuel cycle facilities.

Leakage of Aerosols from a Cell

Leakages of solid and liquid aerosols from a hypothetical cell were determined for puff (instantaneous) and continuous source conditions, using the HAARM-2 code. Cell dimensions were taken as 20 m by 10m by 5 m high; the ventilation rate was assumed to be 5 or 6 air changes per hour; air properties were evaluated at 100 F.

Characteristics of the aerosols dispersed into the cell were varied for the calculations as tabulated on Figures A-1 through A-4. The log-normal size distributions of solid aerosol paticles were based on a



	Particle Size Distribution			
	Dispersed		Leaked	
Curve	MMD	σ_g	~MMD	~σ_g
A	1.25	1.68	1.5	1.6
B	4.0	2.0	2.5	1.6
C	6.05	2.15	3	1.6
D	8.0	2.0	4	1.5
E	10.3	1.76	6	1.4

Figure A-1. Leakage of Solid Aerosol from Hypothetical Cell vs. Puf
Dispersal, for Five Particle Size Distributions.

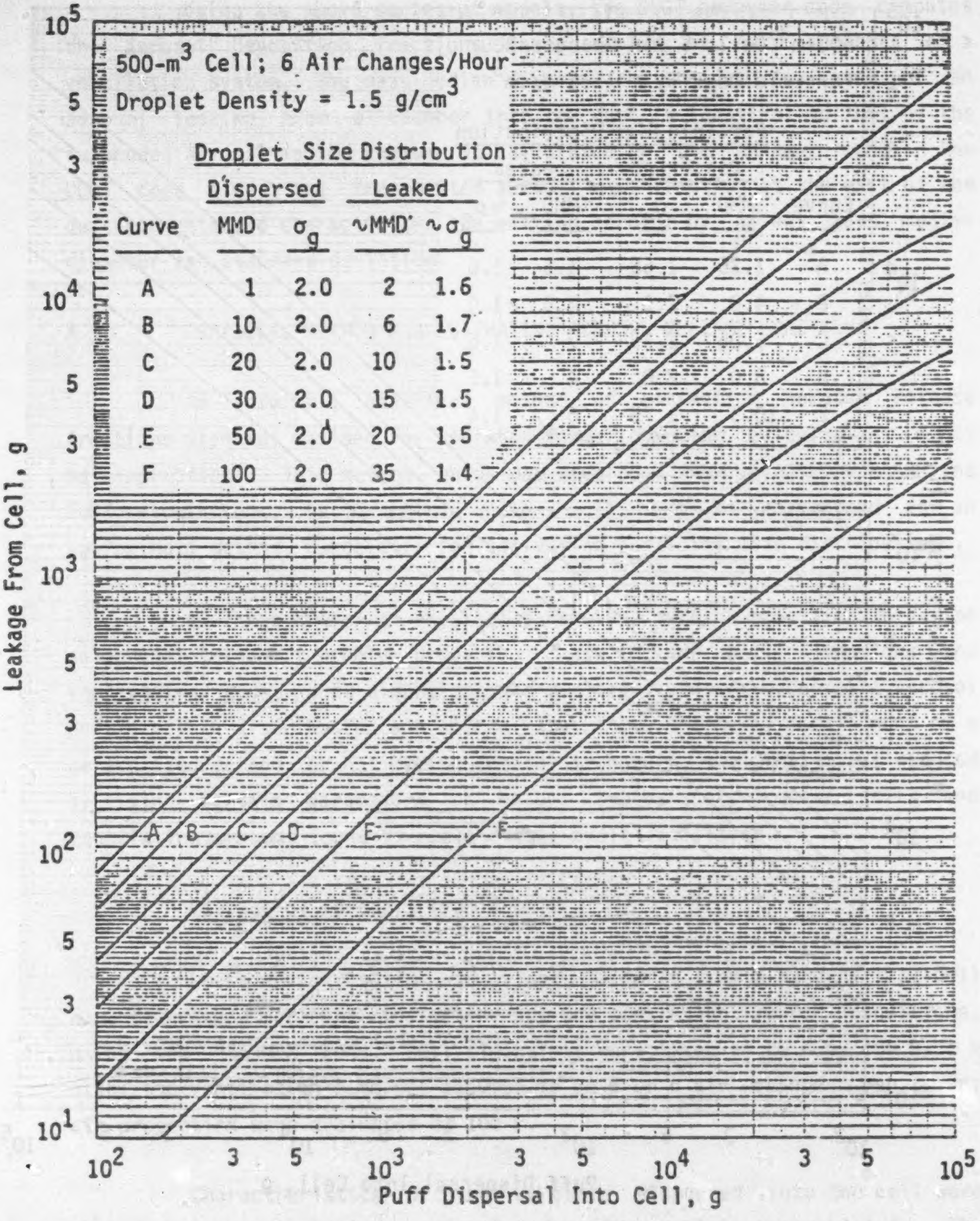


Figure A-2. Leakage of liquid aerosol from hypothetical cell vs puff dispersal, for six droplet size distributions

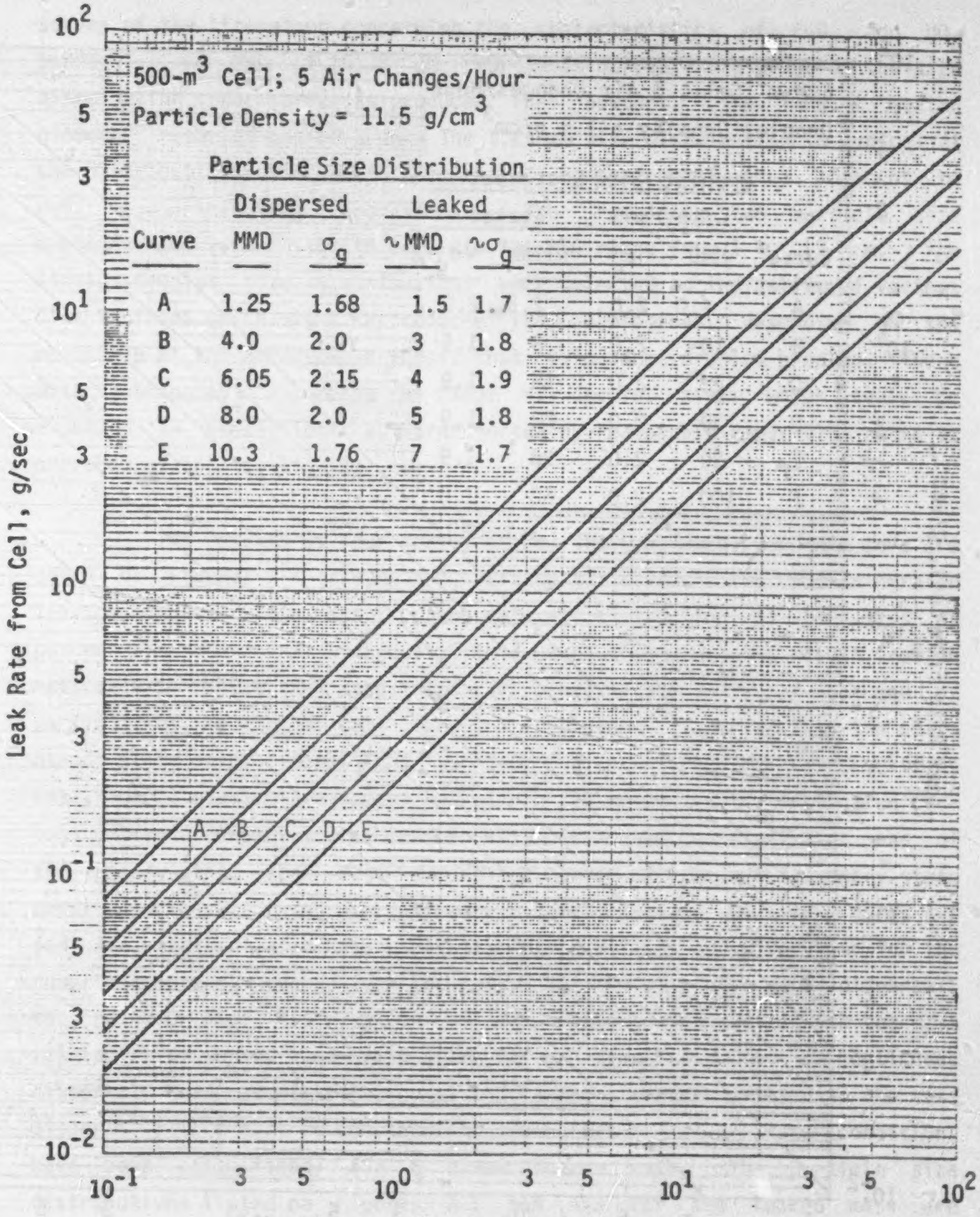


Figure A-3. Leak Rate of Solid Aerosol from Hypothetical Cell vs. Continuous Dispersal Rate, for Five Particle Size Distributions.

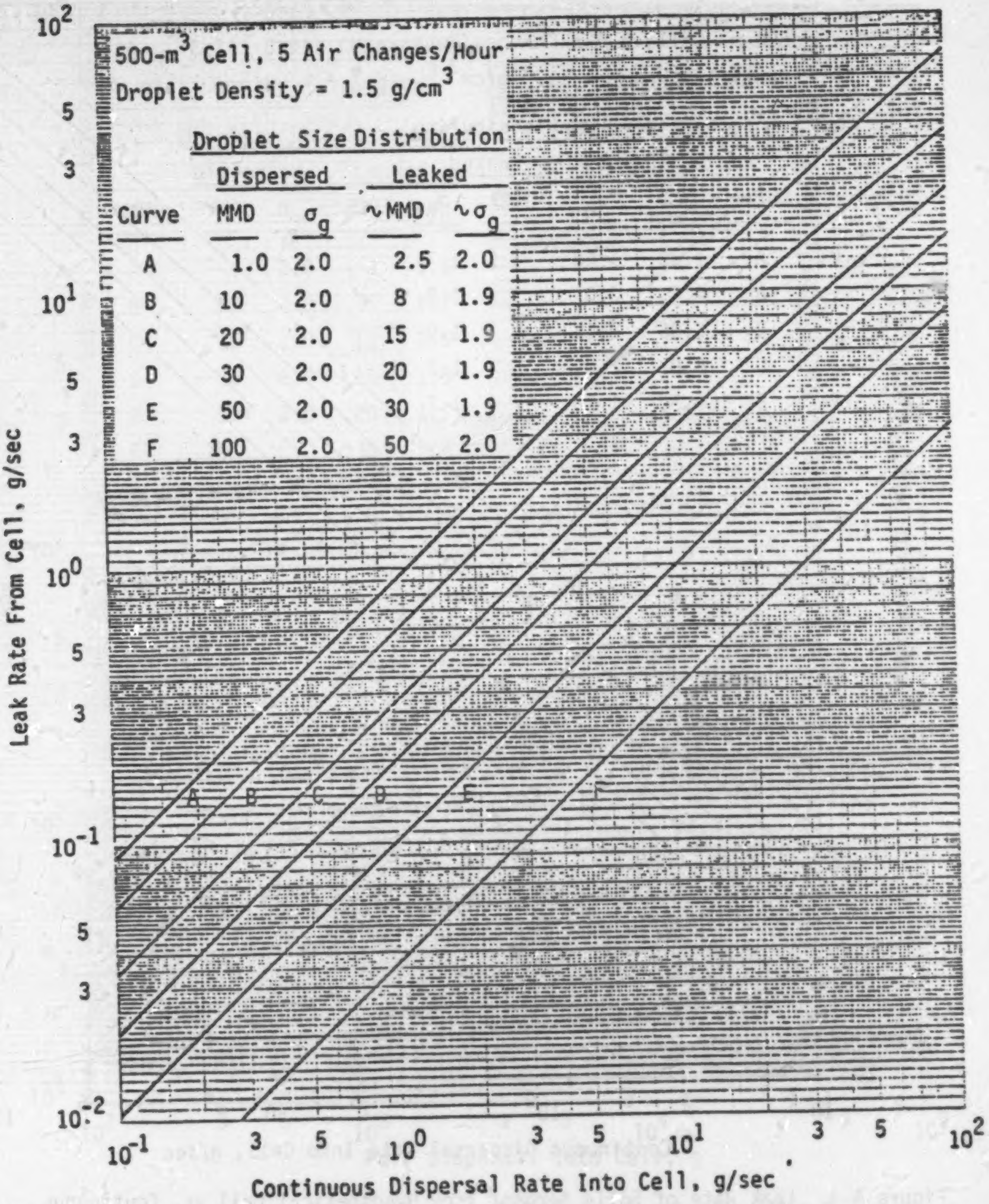


Figure A-4. Leak rate of liquid aerosol from hypothetical cell vs continuous dispersal rate, for six droplet size distributions survey of the literature concerning the characteristics of PuO_2 and UO_2 powders. The MMD of 6.05 μm represents an overall average of the size distribution reported for as-produced fuel powders. The largest median diameter reported was 10.3 μm. The 1.25 μm size distribution is typical of the distributions observed in occupied low-concentration area adjacent to PuO_2 powder-handling operations. The remaining two particle size distributions were chosen to complete the MMD range from 1 to 10 μm. The liquid droplet size distributions were selected as indicative of various distributions which might be produced from explosions, depending on the magnitude of the aerodynamic forces that could cause droplet breakup. These distributions also encompass the range of droplet sizes which could be expected to be levitated and transported by reasonable vapor flow rates at surfaces of boiling liquids.

The results of four series of calculations with the HAARM code are shown in Figures A-1 through A-4. Figure A-1 presents the time-integrated leakage of particulate mass from the cell as a function of the mass of powder dispersed instantaneously into the cell (as could result from an explosion). Figure A-3 presents the steady-state rate of leakage of particulates from the cell due to continuous dispersal into the cell. Steady-state aerosol conditions (airborne concentration, leak rate, settling rate, etc.) usually are approached within 720 seconds after initiation of a constant-rate aerosol source in the cell. It should be noted that use of the steady-state leak rate during the period of approach to steady state conditions results in an overestimate of total leakage. On both Figures A-1 and A-3, estimates of particle size distributions are given also for the resultant aerosols leaked from the cell. For the case of a puff dispersal, the paticle size distribution of the leaked powder varies with the mass initially dispersed and with time after dispersal; for a continuous dispersal, the size distribution of the leaked material varies with the mass dispersal rate but it is constat with time (after steady-state conditions have been established) for a given source rate. The particle size distributions listed on Figures A-1 and A-3 for the leaked mass are representative averages for the stated conditions of source rate, leak rate, particles size distribution of the dispersed material, etc.

Figures A-2 and A-4, for liquid aerosols, are completely analogous to Figures A-1 and A-3 respectively. The preceding comments about dispersal of particulate aerosols into the cell are equally applicable to dispersal of liquid aerosols.

Deposition of Aerosols in a Duct

The deposition of solid and liquid aerosols in hypothetical ventilation ducts was examined for various conditions using the DUCT code. Two duct diameters, representative of the smallest and largest sizes expected in a fuel-handling plant, were used for this general analysis: 30 cm and 250 cm. The air speed in the duct was assumed to be 900 cm/sec (approximately 1800 ft/min) and air properties were evaluated at 100F. Characteristics of the aerosols entering the ducts were varied for the calculations as tabulated on Figures A-5 and A-6. Because the aerosol behavior models used in DUCT do not inlude particle agglomeration, deposition is calculated on the basis of unit aerosol mass. It is not necessary to specify the aerosol mass or mass rate entering a duct.

Nine of the particle size distributions of aerosols entering a duct, as listed on Figures A-5 and A-6, are identical to size distributions of aerosols dispersed into a cell, as listed on Figures A-1 through A-4. The comments in the fourth paragraph above concerning the choice of these distributions again apply. The remaining size distributions listed are representative of some of the aerosols leaked from a cell (as listed in Figures A-1 throygh A-4), since an aerosol exiting a ventilated cell is assumed to enter a ventilation duct.

The results of two sets of calculations with DUCT are shown in Figures A-5 and A-6 for solid and liquid aerosols, respectively. The figures present aerosol deposition fraction as a function of the ratio of duct length to diameter (L/D) for circular, horizontal ducts. Deposition fraction is defined as the fractional part of the mass of aerosol entering a duct which is deposited in the duct, and it may be used to define the mass of aerosol transported through the duct as follows:

Duct Diameter = 30 cm to 250 cm
Air Speed = 900 cm/sec
Particle Density = 11.5 g/cm^3

	Particle Size Distribution			
	Entering Duct		Exiting Duct	
Curve	MMD	σ_g	∿MMD	∿σ_g
A	1.25	1.68	1.25	1.68
B	1.5	1.7	1.5	1.7
C	2.0	2.0	2	1.9
D	3.0	1.8	3	1.7
E	4.0	2.0	4	1.9
F	6.05	2.15	5	2.1
G	10.3	1.76	9	1.7

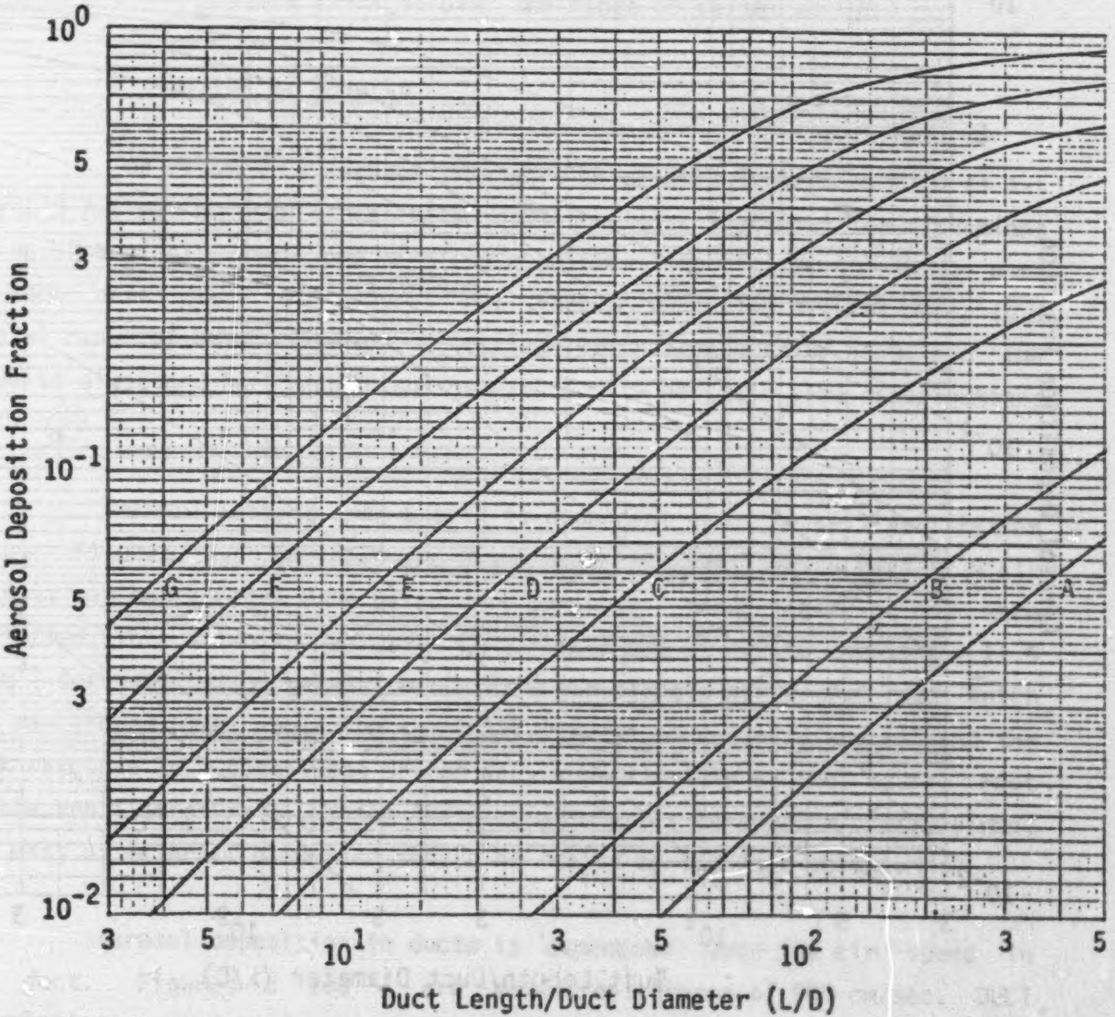


Figure A-5. Deposition of Solid Aerosols in Ducts, for Seven Particle Size Distributions.

Duct Diameter = 30 cm to 250 cm
Air Speed = 900 cm/sec
Droplet Density = 1.5 g/cm^3

	Droplet Size Distribution			
	Entering Duct		Exiting Duct	
Curve	MMD	σ_g	~MMD	~σ_g
A	2.5	2.0	2.5	2.0
B	5	2.0	5	1.9
C	10	2.0	9	1.9
D	20	2.0	15	2.0
E	30	2.0	25	2.0
F	50	2.0	40	1.9
G	100	2.0	70	1.7

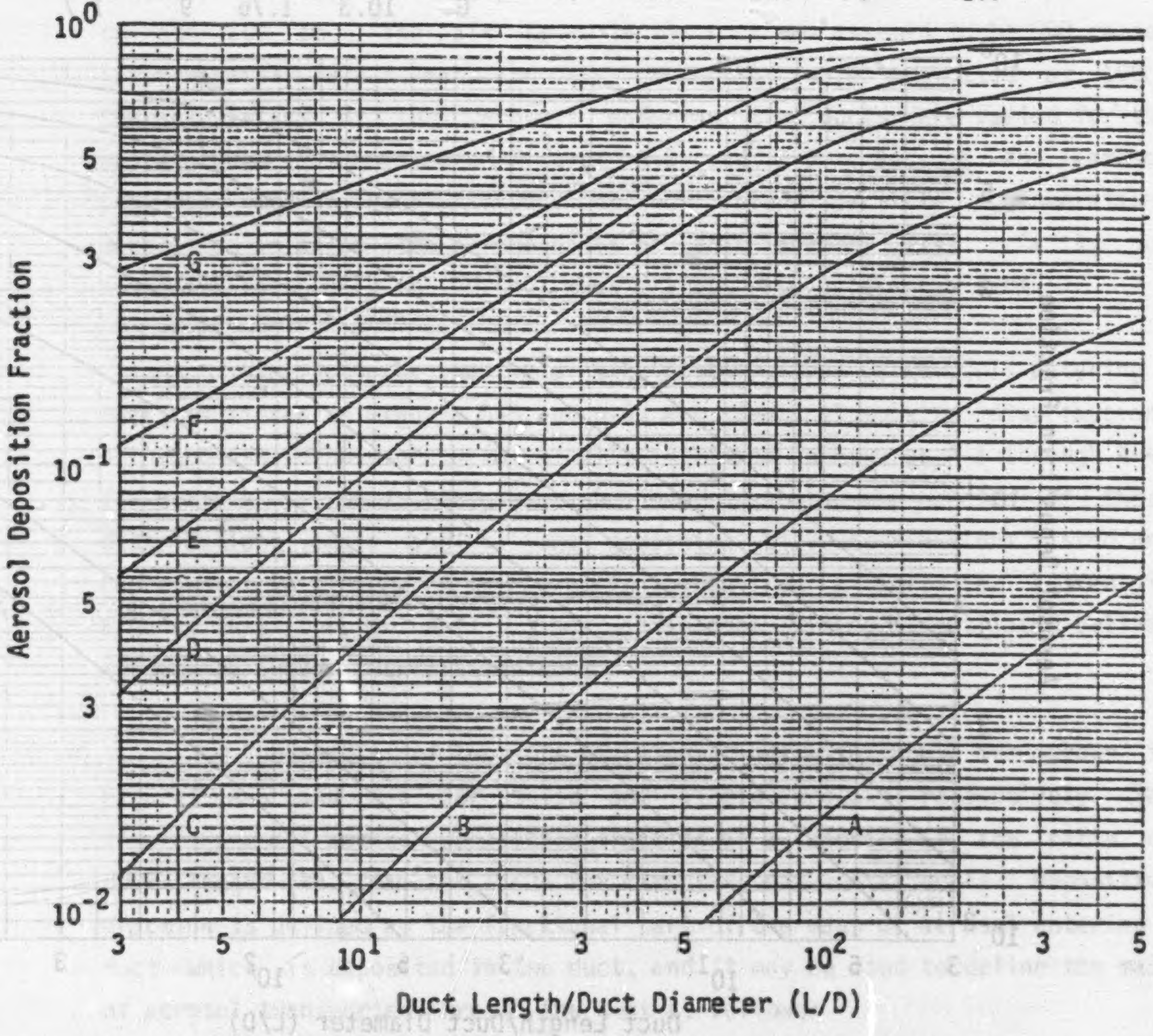


Figure A-6. Deposition of liquid aerosols in ducts, for seven droplet size distributions

$$M_x = (1-f_d)M_e$$

where M_x = mass of aerosol which exits a duct

M_e = mass of aerosol which enters a duct

f_d = aerosol deposition fraction

An approximate size distribution is noted on Figures A-5 and A-6 for the solid or liquid aerosol exiting a duct due to each of the entering size distributions. The exiting size distributions vary with duct dimensions (and therefore with L/D), and the distributions tabulated on Figures A-5 and A-6 are averages over the range of values of L/D.

Discussion of Results

The results of aerosol transport calculations given in Figures A-1 through A-6 may be used to estimate aerosol release fractions for situations in which the cell, duct, and particle conditions are similar to those used in the development of Figures A-1 through A-6. The figures apply to a useful range of MMDs. However, σ_g varies little from a value of 2, and the results discussed here should not be extended to particle size distributions with $\sigma_g \geq 3$.

Aerosol leakage from a cell is dependent upon the cell ventilation rate. Figures A-1 and A-4 are based on a cell ventilation rate of 5 air changes per hour; Figre 2 is based on 6 per hour. HAARM calculations were performed for a solid aerosol (MMD = 6.05 μm, σ_g = 2.15, density = 11.5 g/cm^3) for ventilation rates from 1 to 10 air changes per hour, from which it was found that both the total leakage due to a puff dispersal and the leak rate due to a continuous source vary approximately as the square root of the ventilation rate. Since these results apply to a 500 m^3 cell volume, the mass of material dispersed should be scaled by the room volume.

Aerosol deposition in ducts is dependent upon the air speed in the duct. Figures 5 and 6 are based on a speed of 900 cm/sec. DUCT calculations were done for air speed in the duct from 600 to 1200 cm/sc, which show that deposition varies approximately linearly with air speed. These results may be used as corrections to Figures A-1 through A-6 to extend their applicability to additional situations. In general, the particle size distributions of the escaping aerosols are not very sensitive to ventilation rates or air speeds.

For a given L/D, aerosol deposition is about 40% less in a 250 cm duct than in a 30 cm duct. That is, the deposition is not very sensitive to the particular duct diameter involved. However, the deposition results of Figures A-5 and A-6 may be increased or decreased 10 to 20% to allow for small or large diameters, respectively.

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These results may be used as corrections to Figures A-1 through A-3 [illegible] the [illegible] particle size [illegible] for a given size, aerosol deposition [illegible] less than or 0.30 cm/sec. There [illegible] the particles [illegible] Figures A-5 and A-6 [illegible] small [illegible] diameters [illegible]

A.4 REFERENCES

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2. [illegible]

3. [illegible]

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APPENDIX B

SIZE DISTRIBUTION FOR SPRAY CALCINED HLW

Of the three calcined processes which are highly developed (spray, fluidized bed, and rotary), spray calcination results in the smallest, most dispersable particles. This form was therefore chosen to represent calcine in the evaluation of sabotage consequences.

Information on the size distribution of calcined waste was obtained from two sources. Reference 12 discusses the production and arrangement of all three kinds of calcine, and gives the size range for spray calcine as being from 1 to 100 m. From this information, the mass median diameter* was inferred as being about 10 m, and the geometric standard deviation*, was conservatively assigned a value of 3. (A larger σ_g would tend to put more particles in the respirable range.) These estimates were used for the parametric study of calcined waste released from the hot cell which was presented in Section 1.5.2.

Further more detailed information on the size distribution of calcined waste was obtained via communication with personnel at Battelle Pacific Northwest Laboratories (Reference 14). These data are given in Figure B-1, and were obtained by measuring some actual calcine which was produced. It should be noted tha variation in the particle sizes can be obtained by changing process parameters so that this data is representative but not definitive.

The following text accompanied the figure:

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*Reference 13 discusses the meaning of various parameters relating to particle size distributions.

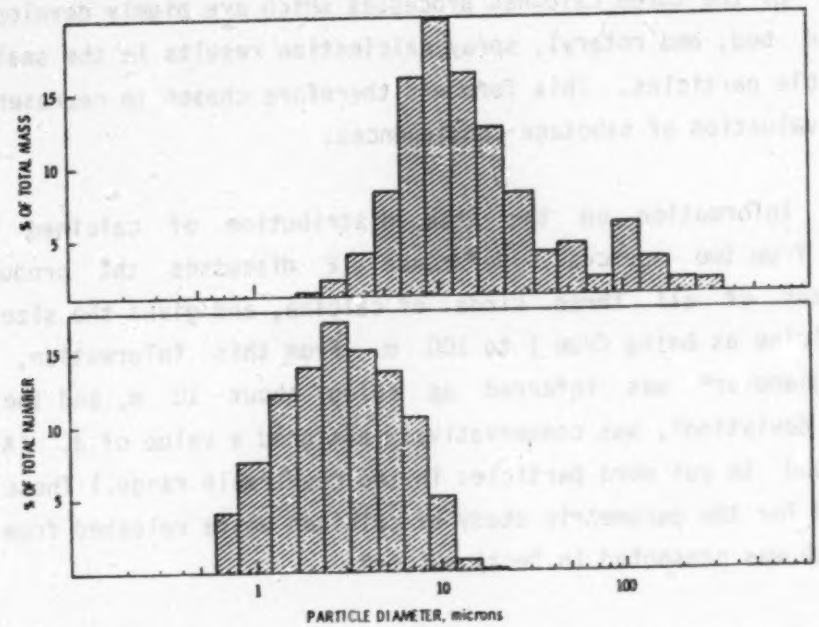

Figure B-1. Spray calcine size distribution

"The product of calcining simulated high-level liquid waste in the heated wall spray calciner is a very fine, dry powder consisting mainly of metal oxides with some alkali metal nitrates and waters of hydration present.

Calcine particle size distributions were obtained by U.S. Standard sieve analysis, Fisher Subsieve analysis, Zeiss particle size analyzer, and Quantimet 720 projection size distributions. The results are presented as histograms in Figure B-1. This presents the size distribution both in terms of percent of total particles and percent of total mass. While 65% of the total number of particles is in the "diameter" range of 1 to 5 μm, these particles account for only 15% of the mass. Only 17% of the total particles is of "diameter" 6 to 20 μm, but they account for 75% of the mass. The large particles, over 1 mm, were analyzed and found to be of the same composition as the rest of the calcine except for higher water content and associated nitrate."

These data were used by reading values off both the number distribution and mass distribution scales, then correlating them since each distribution is more sensitive in a different range. The resulting numbers which were obtained were used as the calcined waste distribution.

It was found that, using these numbers, only 15% of the calcined material, by mass, had an aerodynamic diameter in the respirable range (<10 μm).

The product of calcining simulated high-level liquid waste in the heated wall spray calciner is a very fine, dry powder consisting mainly of metal oxides with some alkali metal nitrates and waters of hydration present.

Calcine particle size distributions were obtained by U.S. Standard sieve analysis, Fisher Subsieve analysis, Coulter particle size analyzer, and Quantimet 720 production size distributions. The results are presented as histograms in Figure B-1. This presents the size distribution both in terms of percent total particles and percent of total mass. While 60% of the total number of particles is in the diameter range of 2 to 5 μm, these particles account for only 15% of the mass. Only 12% of the total particles is of diameter [illegible] μm, but they account for 45% of the mass. The large particles [illegible] were analyzed and found to be of the same composition as the [illegible] higher water content and associated nitrates.

These data were used for [illegible] both the number distribution and mass distribution [illegible] distributions [illegible]. The resulting [illegible] were used as the [illegible] size distribution.

It was found that, using these numbers, only 15% of the calcined material, by mass, was in [illegible] the respirable range (<10 μm).

APPENDIX C
DEPOSITION FRACTIONS FOR RELEASES IN MINE

This appendix describes the method used to calculate the fraction of material released from the mine after hoist drop events. In summary, the "completely stirred" formula for particle settling was used repeatedly using multiple particle size classes for each leg in the mine, from source point to vent, to determine the release fraction and size distribution of material released from the mine.

Figure C-1 gives a schematic of the mine dimensions and ventilation flowrates assumed for the calculations. Starting from the release point at the base of the hoist, there is a 1200' section of 22-ft high by 36-ft wide tunnel leading to a branch point. A short, 300-ft segment leads from this branch point to the base of the vertical exhaust duct below the stack. A longer segment leads to a parallel set of emplacement rooms, then back to the vertial duct below the stack.

The Reynolds numbers for ventilation air flowing through the various segments of the mine were calculated, and it was found that the flow was highly turbulent in all locaions. Based on this turbulence, the "completely stirred" formula for settling, given by Davies* was used. According to this formula, which has been used to calculate the loss by settlement of dust in a coal mine at various distances away from the source of the dust, the airborne concentration will be reduced by the factor $\exp(-v_p x/wh)$ in a distance x, where v_p is the particle fall velocity, w is the air speed along the duct, and h is the height of the duct.

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*C.N. Davies, editor, Aerosol Science, Academic Press, London, p. 401-402 (1966).

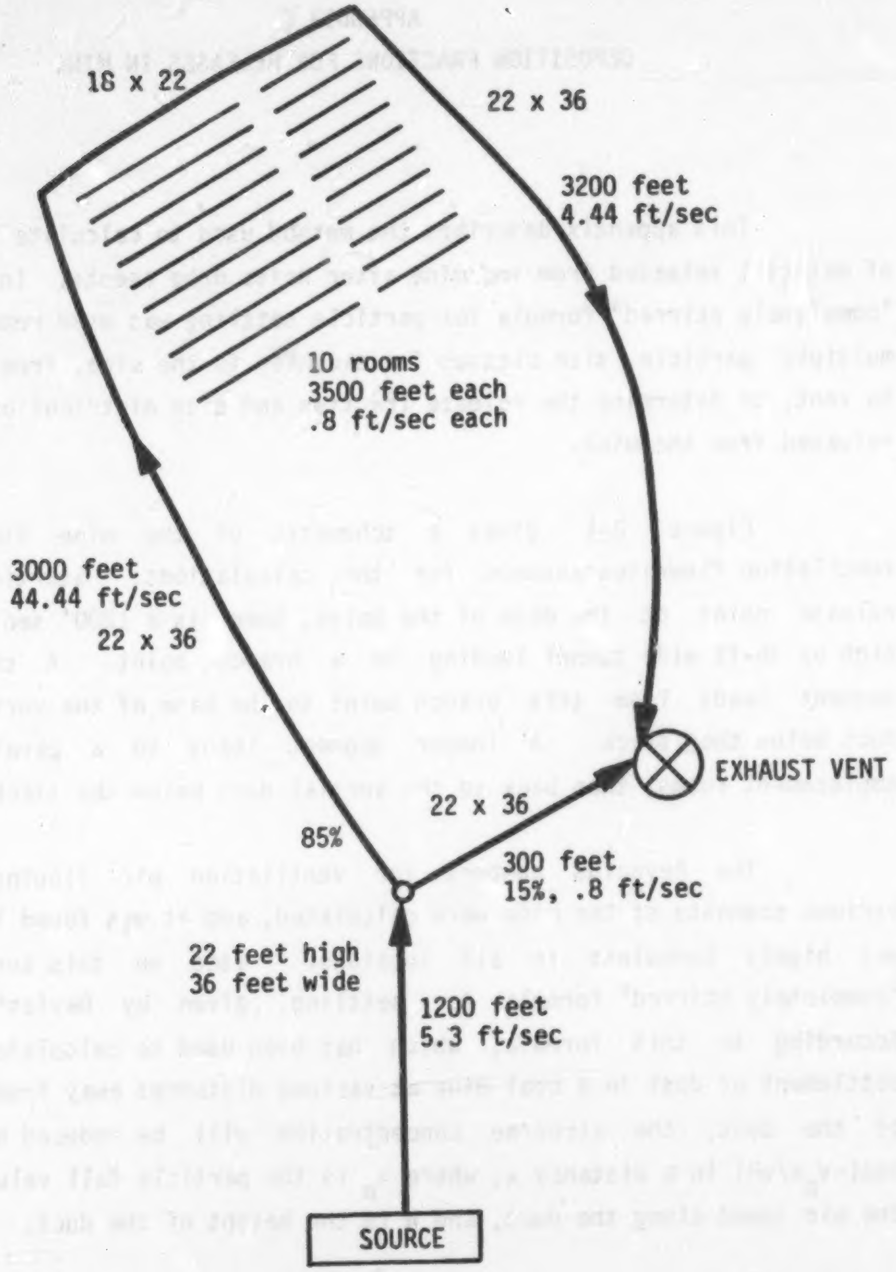

Figure C-1. Mine schematic

In the above formula, the particle fall velocity, v_p, is a function of particle size and density. The particle size distribution was therefore divided into a number of size classes. (Nineteen size classes were used for the calcined waste calculations, while fifty size classes were used for the spent-fuel and vitrified waste calculations. A small computer code was written to aid in the analysis.) The fall velocity was then calculated by the following expression,

$$v_p = \left[\frac{4}{3}\, a^{1+C_2} \frac{\rho_p}{\rho_a}\, g/C_1 \nu^{C_2}\right]^{\frac{1}{2-C_2}}, \text{ cm/sec}$$

In the above, a is the particle diameter in cm, ρ_p is the particle density, g/cm^3, ρ_a the air density, (0.001225 g/cm^3), g is the gravitation constant (981 cm/sec^2) and ν is the air viscosity (0.15 cm^2/sec). The constants C_1 and C_2 are dependent on Reynold's number, R_e, where

$$R_e = \frac{av_p}{\nu} \text{ (dimensionless)}$$

with the values

$$C_1 = \begin{cases} 24 & Re<1.32 \\ 18.5 & 1.32<Re<500 \\ 0.44 & 500<Re<2x10^5 \\ 0.20 & 2x10^5<Re \end{cases}$$

$$C_2 = \begin{cases} 1 & Re<1.32 \\ 0.6 & 1.32<Re<500 \\ 0 & 500<Re \end{cases}$$

The above expression for v_p was derived by equating particle weight and drag forces for a spherical particle falling at equilibrium velocity, i.e.,

$$\frac{4}{3}\pi\left(\frac{a}{2}\right)^3 \rho_p g = \frac{1}{2}\rho_a v_p^2 \pi\left(\frac{a}{2}\right)^2 C_d$$

where C_d is the drag coefficient for sphere given by Bird, Stewart and Lightfoot,

$$C_d = \begin{cases} 24/Re & Re<0.1 \\ 18.5/Re^{0.6} & 2<Re<500 \\ & \\ 0.44 & 500<Re\leq 2x10^5 \\ 0.2 & Re>2x10^5 \end{cases}$$

and solving for v_p. (The modified Reynold's number breakpoint of 1.32 was derived by solving for the value of Re at the drag coefficient crossover point, i.e., $24/Re=18.5/Re^{0.6}$.)

The size distribution for the spray calcined waste was derived from Figure B-1, which was obtained from Mr. Fred Miller of Pacific Northwest Laboratories. Figure B-1 gives both the mass and number distributions. The number and mass distributions were correlated (mass is proportional to number times diameter cubed) to derive the 19-size-class representation of the data.

A log-normal size distribution was assumed for the spent fuel and vitrified waste fines released from the canisters in the hoist drop events. The spent-fuel fines were assumed to have a mass median diameter (MMD) of 1.25 microns and a geometric standard deviation (σ_g) of 1.08 microns. The vitrified waste fires were assumed to have a MMD of 1.5 microns and a σ_g of 2 microns. Table C-1 summarizes these data and gives results of the calculations just described.

Table C-1. Deposition For Releases in Mine

	Spent Fuel	Vitrified Waste	Calcined Waste
Amount Dispersed at Bottom of Hoist Shaft	0.1% of 4 Assemblies	1% of Contents of 4 Canisters	100% of Contents of 4 Canisters
Size Distribution Assumed*	MMD = 1.25μ σg = 1.08	MMD = 1.5μ σg = 2	Actual Data Per Figure C-2, MMD ∿ 10μ σg ∿ 2μ
Particle Density (g/cm^3)	11	3	4
Respirable Fraction	1.0	0.97	0.15
Fraction of Respirable Material Released From Facility	0.68	0.78	0.44
Fraction of Initially Released Material Released From Facility	0.68	0.76	0.066

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*Note that the size distribution data exists only for calcined waste. Note also that the size distribution for calcined waste can vary with calcine process parameters, with MMD values varying from 10 to 120μ. The size data for spent fuel and vitrified waste were chosen so that almost all material would be in the respirable range (less than 10μ aerodynamic diameter), consistent with earlier assumptions.

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This report provides the results of a study to assist the NRC in establishing a technical basis for the examination and resolution of safeguards issues related to high-level waste repositories. In this study, safeguards requirements for a NRC-licensed high-level geologic waste repository are proposed. The high-level waste repository is assumed to accept wastes from any of several commercial light water power reactor fuel cycles including once-through (in which spent fuel is buried), uranium only recycle (in which reprocessed wastes including cladding hulls, fission products and transuranic wastes are buried), and uranium-plutonium recycle.

The security requirements are assumed to result from three potential threats to public health and safety: on-site radiological sabotage, theft for the purpose of off-site radiological dispersal, and theft for the purpose of producing a nuclear explosive. For the latter threat objective, i.e., theft for production of a nuclear explosive, both domestic and international safeguards requirements are considered.

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